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James Ivil Karr

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16. ABSTRACT
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A "before-and-after" study method was used to evaluate 39 grooved cement concrete projects on California State highways. The 34 lane-miles of these projects represent California's grooving effort since its conception in the early 1960's until early 1968.

A wet pavement condition was defined to exist during any hour 0.01 inch or more precipitation occurred. U.S. Department of Commerce's Environmental Data Service furnished computer tapes from which was developed an isohyetal map of California that reflects the percent of wet time. This was the basis for estimating wet accident rates.

The 3/4-inch spaced grooves gave the best "after grooving" accident reduction. Wet accidents decreased 75% and total accidents decreased 37% despite a 17% increase in traffic and wetter after periods on those 14 projects grooved on 3/4-inch centers.

17. KEYWORDS
Pavement serration, pavement grooving, wet pavement corrections, minor safety improvements, slippery pavements, pavement wear, skid resistance

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evaluation of minor improvements

grooved pavements (part 8)

report by: James Ivil Karr

DECEMBER 1972

71-22

PREVIOUS MINOR IMPROVEMENT STUDY RELEASES

Part 1 - FLASHING BEACONS

Part 2 - SAFETY LIGHTING

Part 3 - DELINEATION

Part 4 - GUARDRAIL

Part 5 - LEFT-TURN CHANNELIZATION

Part 6 - SIGNS

Part 7 - TRAFFIC SIGNALS

Part 9 - OPEN GRADED ASPHALT CONCRETE OVERLAYS

Part 10 - MISCELLANEOUS

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December, 1972

Mr. R. J. Datel
State Highway Engineer
Sacramento, CA

Dear Sir:

Submitted herewith is the report "Evaluation of Minor Improvements - Part 8, Grooved Pavements".

Study under general direction of . . . . . W. R. Juergens

Principal Investigator . . . . James Ivil Karr

Project Assistant. . . . . Milburn Guillory

Report by. . . . . James Ivil Karr

Sincerely,

A. C. ESTEP
Traffic Engineer

FOREWORD

The objective of this report is to provide some background on the State-of-the-art of grooving pavements to prevent accidents. It is basically a before-and-after study of California's accident experience with grooving since its concept in the early 1960's until early 1968.

Unfortunately, the lead time necessary to conduct the after phase of the study prevented inclusion of the State's more current grooving pattern. That pattern, a narrow .095" wide groove on 3/4" centers, was instituted in 1968. To alleviate this shortcoming, a follow-up study has been initiated to study grooving through June 1971. The follow-up study will include some 150 lane-miles of grooving. The follow-up report should be finalized by late 1973.

A preliminary review of data for the follow-up study confirms the wet accident reductions found in this report. The follow-up data shows identical changes: that grooving has no effect on dry accidents one way or the other.

PRELIMINARY DATA OF FOLLOW-UP STUDY

		Dry Accidents				Wet Accidents			
		F&I		PDO		F&I		PDO	
Follow-up Study	Before After	677 529	(-22%)	925 1,325	(+43%)	171 49	(-71%)	237 112	(-53%)
Control Section	Before After	7,186 5,590	(-22%)	10,545 15,230	(+44%)	1,388 974	(-30%)	2,241 3,196	(+43%)

( ) percent change

In more recent years, the motorcycle population has increased considerably and the question of their safety on grooving has been raised rather strongly. Since there were only 15 motorcycle accidents in this study, we were not able to answer that question in this report. The follow-up study shows no change in motorcycle accident experience after grooving. The preliminary data shows 45 motorcycle accidents before and 46 after grooving despite a tremendous increase in the number of motorcycles during recent years.

The investigators would like to express their appreciation to Mr. Eugene E. Farnsworth of District 07, Division of Highways, State of California, for his assistance and experience in pavement grooving.

Mr. Richard D. Tarbel of the National Weather Service provided the precipitation data necessary for determining the percent of time pavement is wet.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Concluded)

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

AC	Asphalt Concrete
ADT	Average Daily Traffic
CC	(Portland) cement concrete
DAR	Dry accident rate
K	Road use factor
MV	Million vehicles
MVM	Million vehicle miles
$Pw_{0.01}$	Percent of wet time based on count of hours with $\geq$ 0.01" precipitation
R	Seasonal prediction factor
ROR	Run-off-road accidents
WAR	Wet accident rate
WE	Wet exposure in MVM

I. SUMMARY AND RECOMMENDATIONS

A. Summary

Thirty-eight grooved cement concrete projects were studied for two years before and two years after grooving. One other project was studied on a one-year-before/one-year-after basis.

The 34 lane miles of grooved pavement studied represented California's grooving experience from its conception in the early 1960's until February 1968. All known grooving susceptible to study was included.

Most of the projects studied were short projects. Twenty-three of the 39 projects were less than 1/4 mile long. Only 4 of the projects were 1/2 mile long or longer.

Nine different grooving patterns were studied. Current specifications specify 3/4" spaced grooves and projects with those spacings yielded the best reductions. Fourteen of our 39 projects had 3/4" spaced grooves.

There were 1,133 accidents in the before period compared to 904 accidents in the after period. This was a 20% reduction in accidents despite a 17% increase in traffic. The projects were exposed to 365 million vehicle miles of travel in the before period and 429 million vehicle miles in the after period. (The 3/4-inch spaced grooves yielded a 37% reduction in accidents.)

(California has over 1,200 lane miles of grooved pavement of which approximately 1,000 lane miles has been completed since early 1968. Some of the current projects are as much as 5 miles long.)

Wet pavement accidents were most susceptible to correction and they were reduced 70%. Wet pavement accidents decreased from 535 accidents before grooving to 158 after grooving despite wetter after periods.

Dry accidents increased 28%. When allowance was made for the experience of the adjacent sections, the increase was 15%. A follow-up study of some 150 lane miles of grooving placed after February 1968 indicates that grooving does not effect dry accidents one way or the other.

Fatal accidents were cut in half. There were 21 fatal accidents in the before period and 10 in the after period. However, fatal plus injury reductions were about the same as PDO reductions. The severity of accidents after grooving was about 10% less than the statewide average.

Overall, 28 of the 39 projects improved. Fourteen of those improved significantly. Two projects significantly worsened. There were reductions in accidents as far as 0.2 mile downstream of projects.

Little information could be developed relative to traffic density, wear and friction factors. Therefore, these factors were not studied.

California's earlier grooving indicates 1/8" deep grooves (in cement concrete pavements) may be effective in excess of 10 years. Life expectancy of grooved asphalt concrete is pretty variable but can be more than 5 years for old, brittle AC pavements. Grooves are being cut 3/16" deep at present on an experimental basis. It is hoped we might gain 50% more life for less than 50% extra cost.

Stopping distances (from 40 mph) were some 50 feet less on grooved wet pavement than on ungrooved wet pavement. Grooving also tended to make skids "controlled skids".

We defined a wet pavement as any pavement that has been subjected to 0.01" or more of precipitation within an hour. Seasonal factors were developed from continuous recording weather stations and continuous recording traffic count station data.

B. Recommendations

Treatment of the pavement by grooving should be performed on no less than 500 feet (4). In addition, treatment should be carried well beyond such highway features as intersections, superelevation runoff, and sag vertical curves when such features are near.

For most pavements, a satisfactory groove pattern would be 1/10" wide, 1/8" deep and spaced on 3/4" centers.

The equation: $WAR_{AFT} = 1.5 + 3 \cdot DAR_{BEF}$ should be used to predict after wet pavement accident rates. Dry accident rates should be assumed unchanged and severity should be assumed to change to a normal condition.

(_) denotes reference material - Page 53

II. INTRODUCTION

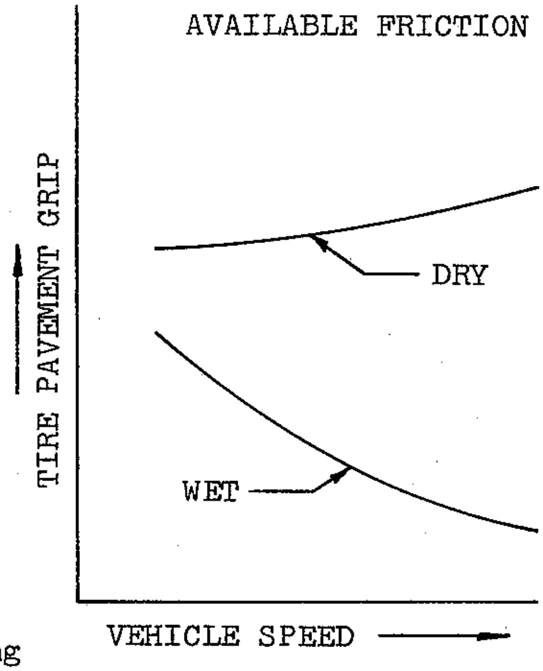
A. General

In the 1950's, the California Division of Highways became aware that some sections of older freeways were having an unusual number of wet-pavement accidents. There were over 14,000 accidents on wet California State highways in 1971. These accidents were typically skidding accidents.

A prevalent driver error on wet roads is that of misjudging the gripping ability of his tires to the road. He does not realize that when pavement is wet the "gripping" capacity of tires decreases with speed. Figure 1 shows the opposing curves of dry and wet pavements, according to Kummer and Meyer. (1)

FIGURE 1

AVAILABLE FRICTION



Tire-pavement interlocking values are often reduced by one or more of the following conditions (1):

(_) denotes reference material - Page 53

1. Pavement - polished by traffic.

2. Weather - excessive water depth on pavement, excessive temperature, snow or ice on pavement.

3. Vehicle - bald tires, low tire pressures.

NASA Langley Research Center (2) has studied the phenomena "hydroplaning". Hydroplaning usually results from a combination of the above three conditions. According to their studies, hydroplaning can be expected to occur when water depth on the road exceeds tire tread depth and a vehicle's speed (MPH) exceeds "10 times the square root of the tire pressure (PSI)".

B. Anti-skid Treatments

New finishing techniques are being tried on Portland cement concrete in an effort to increase and extend the life of its skid resistance. Stiffer brooms and heavier burlap drags are giving a rougher (almost grooved) appearance. Reducing the amount of surface water, reducing the amount of finishing and using more improved curing compound are adding surface strength to pavements.

Seeding the surface with slag aggregate as well as other types of aggregates is also being tried in an effort to extend the skid resistant life of PCC pavements.

(_) denotes reference material - page 53

However, regardless of how much you extend a pavement's skid resistant life, a day ultimately comes when the surface becomes polished. In Los Angeles where some freeways are subjected to 200,000 AADT this can happen in less than 5 years.

One common method used by the California Division of Highways to increase the skid resistance of an existing pavement is to groove the surface. The grooves are cut parallel to lane lines by diamond-tipped blades. District 07 (Los Angeles area) has been doing the majority of pavement grooving in California. Their grooving experience dates back to 1963. There are over 1,200 lane miles of grooved California State highways.

Some research effort has been directed toward putting grooves into newly constructed pavement surfaces before they are opened to traffic. Rubber fins and steel teeth were towed behind the paving machine but depth of groove could not be controlled in the plastic surface. The next trial was to groove the pavement shortly after the plastic stage. Two miles were grooved successfully 60 days after concrete placement. A future project will attempt to do the grooving 10 days after concrete placement.

Another method used in California to gain skid resistance is to overlay the existing surface with a new surface. This is usually accomplished with an open-graded asphalt concrete blanket. See Part 9 of the "Evaluation of Minor Improvements" study for an analysis of open-graded asphalt concrete overlays.

One of our districts recently scorched an asphalt concrete surface at two wet pavement accident concentration sites with heater planers and torches. Epoxy adhesives and other surface dressings have been used. These all seemed to be very effective in reducing wet pavement accidents and bear future study. Lack of data prevents our analysis of these miscellaneous skid treatments **at this time.** Corrective measures are further discussed in Mr. John Beaton's report (3).

The specific purpose of this Part 8 is to evaluate the effectiveness of grooving in eliminating wet pavement accidents.

C. Length of Grooving Projects

The length of the grooved lanes studied varied from 0.04 to 1.31 miles long. Twenty-three of those projects included in this study were less than 0.25 mile long; 34 were less than 0.50 long. The Federal Highway Administration recommends a minimum length of 500' for corrective work (4).

(_) denotes reference material - Page 53

Many of the original sections of grooving have had to be extended. This meant another small project when one large (initial) project could have "prevented" many wet accidents in adjacent sections.

It would appear that a "spot" concentration of wet accidents is often a cue of an area problem in its initial stage.

D. Groove Dimensions

The spacing of our grooving patterns varied from 3/8" to 1". Spalling was a major problem with the narrower spacings. The 3/8" and 1/2" spacings had extensive spalling while there was only slight spalling at the 3/4" spacing. Except in "Chains Required" areas, grooved areas with 1" spacings did not spall. Coefficients of friction were considerably less for the 1" spaced grooves than for either 1/2" or 3/4" spacings. Since the 3/4" and 1/2" spacings had about the same coefficient of friction; the 3/4" spaced grooves seem preferable (5).

(_) denotes reference material - Page 53

A 1/8" groove depth and width seem sufficient. Most of our patterns were within ±1/16" of this 1/8" in both width and depth. This corresponds to results found by the British Road Research Laboratory (6). They stated in part "...grooves (in tire tread) 2/10" wide gave very good results. No further improvement was evident if the grooves were made still wider".

California's current grooving specification states in part:

> "...Grooving blades shall be 0.095 inch wide ±0.003" and shall be spaced 3/4 inch on centers. The grooves shall be cut not less than 1/8" nor more than 1/4" deep. The grooves on bridge decks shall be cut not less than 1/8" nor more than 3/16" deep..."

See Appendix B for the complete Special Provisions for grooving existing concrete pavement.

Two of our study projects had grooves cut 3/16" deep. District 07 (Los Angeles area) engineers are specifying 3/16" as a minimum depth during the early months of 1972. This could forstall regrooving at least another five years.

Another possible concept that could change future grooving specifications might be to allow grooving of any areas that are smooth or polished as a result of grinding or "bump

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(_) denotes reference material - Page 53

cutting". Present Standard Specifications require such areas to have a coefficient of friction of not less than 0.30 after grinding. Some experimental bump cutting has been done successfully by inserting a larger diameter blade onto the cutting head every 3/4". Faster wear of that blade is the biggest problem.

E. Motorcycle Rideability

Rideability tests on grooves 1/4" wide revealed they will cause a "strange feeling" to motorcyclists. District 07 (with the assistance of the Los Angeles Police Department) tested motorcycle riding characteristics in 1966 and again in 1968. The Materials and Research Department of the California Division of Highways published a report on motorcycle rideability (7), conducted jointly with the California Highway Patrol, in 1969.

The following excerpt quoted from the 1968 test is typical of all three tests:

> "...No problems of maneuverability were experienced on this serrating pattern (1/10-inch wide grooves). Numerous turning movements and lane changes were made with no problems or loss of control..."

It was expressed (during that 1968 study) that grooving was acceptable for the safe operation of motorcycles. Knobby tired cycles and lighter cycles were the most sensitive to

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(_) denotes reference material - Page 53

grooves. The narrower grooves yielded a more comfortable ride to motorcyclists.

Tests demonstrated unmistakably safer stopping characteristics for motorcycles traveling over wet, grooved pavement than over wet, ungrooved pavement. Ordinarily, a motorcycle will go down when braked on a wet pavement. The test cycles not only stayed up when braked on wet, grooved pavement; but skidded in a straight line along the grooves.

F. Stopping Distance

Limited dynamic stopping distance tests were conducted by District 07 on grooved and ungrooved pavements. Tests were made with treaded tires and smooth tires. All test vehicles were braked from 40 mph to a stop. The difference in stopping distance between dry grooved pavement and normal dry pavement was less than a car length (grooved-69' vs. normal-58'). It should be remembered that there is 1/10" less pavement in every 3/4" (or 13% less pavement surface). The vehicle skidded 80-100' on wet, grooved pavement but skidded in excess of 140' on wet, ungrooved pavement. The direction of the skid over the grooves was controllable and straight.

G. Pavement Life

Those urban highways subjected to high traffic exposure often polish in 3 to 5 years. California's experience also indicated that grooved cement concrete pavement exposed to tire chain wear spall and wear down into "ruts" in less than 2 years. The State of Colorado (8) had much the same loss of grooves on cement concrete pavement. There, the wear was attributed to studded tires.

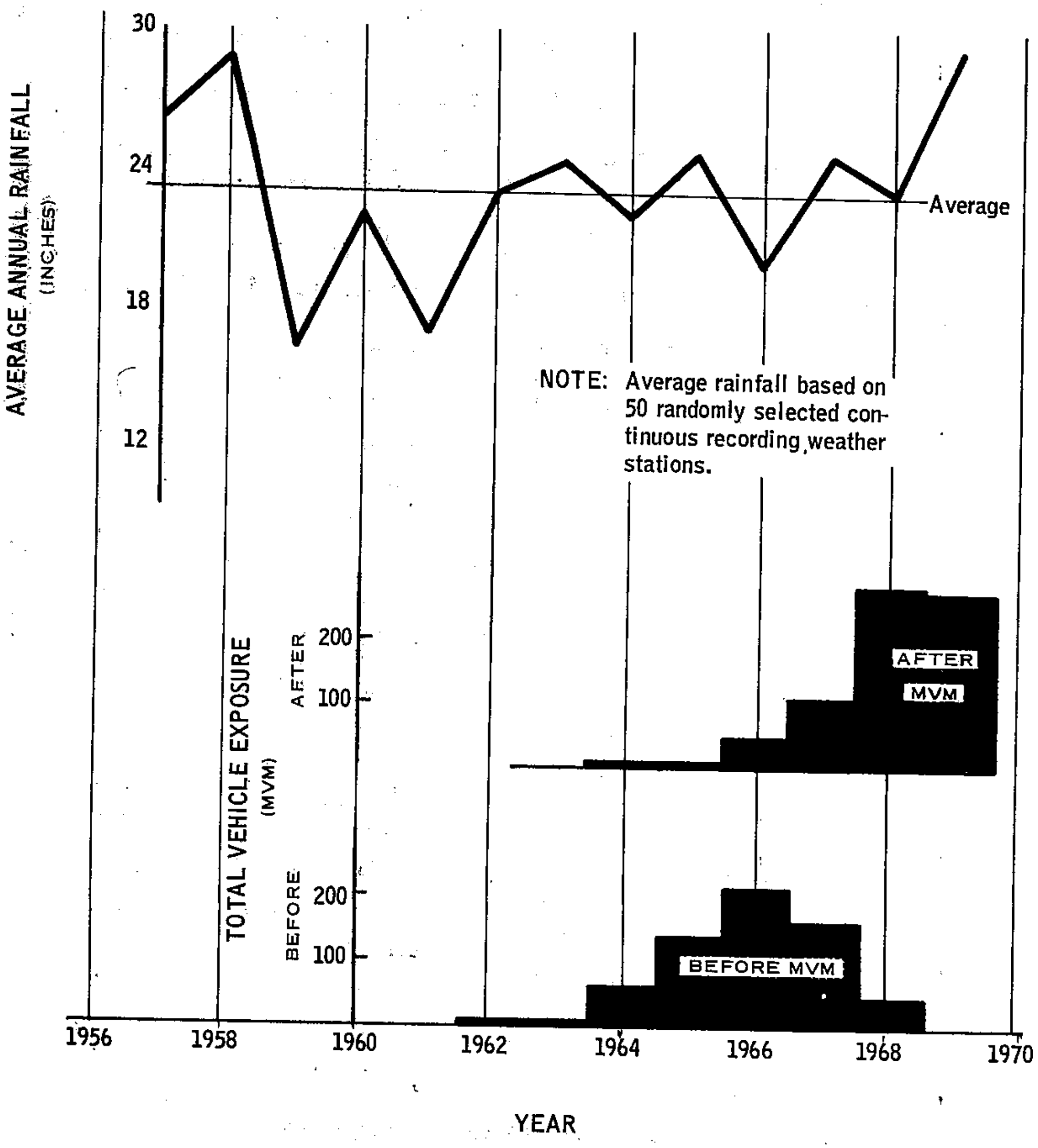
The effect of a concrete pavement's aggregates on the life of grooving was not included in this study. However, most of our grooving experience was based on freeways in the Los Angeles area and the aggregate in that area is generally softer than throughout the rest of the State.

California uses 10 years as an estimated life for cement concrete pavements grooved 1/8" deep.

(_) denotes reference material - Page 53

Figure 2

TOTAL VEHICLE EXPOSURE COMPARED TO AVERAGE ANNUAL RAINFALL



III. TRAFFIC VOLUMES AND RAINFALL

A. Traffic Volumes

All but one of the grooved cement concrete projects were studied for 2 years before and 2 years after grooving. During the 2-year interval between centers of the before and after periods, traffic increased about 17% at our project sites. There were 365 MVM's during the before periods and 429 MVM's during the after periods. Annual MVM's of exposure are shown on Figure 2.

Total traffic exposure of our projects was determined by taking the average ADT of each before and after period and using each of those annual ADT's for the appropriate period.

B. Rainfall

In addition to an increase in traffic, there is another major factor to consider - weather. Analysis of adjacent sections and comparison of wet exposures should account for much of weather's effect on accidents. Figure 2 was developed from a sample of 50 weather stations. They may or may not be representative of average annual rainfall in California; however, the point of interest to us is the year-to-year change in weather and these 50 weather stations indicate this change.

The bulk of "before" study periods was during the 3 years 1965-1967. By our Figure 2 these years were about average. On the other hand, most of the "after" study periods were during the wetter years 1968-1969.

C. Traffic Exposed to Wet Pavement

Grooving is done to correct a wet accident problem. Therefore, a measure of wet exposure or the number of vehicle miles on wet pavement becomes a parameter not heretofore considered in the "Evaluation of Minor Improvements" study. Another report, "A Method to Determine the Exposure of Vehicles to Wet Pavements", (9) goes into the details of developing wet exposures for this project.

Basically, U. S. Department of Commerce environmental data (10) was used to identify the number of hours having 0.01" or more rainfall at some 350 continuous recording weather stations in California. An isohyetal map of California was developed with lines through points of equal percent of time that there was 0.01" or more precipitation (See Figure 3).

Since California's weather and traffic are seasonal with peaks at opposing times of the year, we had to adjust the "percent of wet time" indicated by Figure 3. In formula, wet exposure becomes:

$$WE = K \cdot Pw_{0.01} \cdot AADT \cdot T \cdot L \qquad \text{(Eq. III-1)}$$

WE = wet exposure (million vehicle miles)

K = 0.86 for California 'statewide'; K approaches 1.0 for urban roads; and 1.1 for desert roads

$Pw_{0.01}$ = ratio of wet time (decimal)

AADT = average annual daily traffic (million vehicles)

T = time length of study period (days)

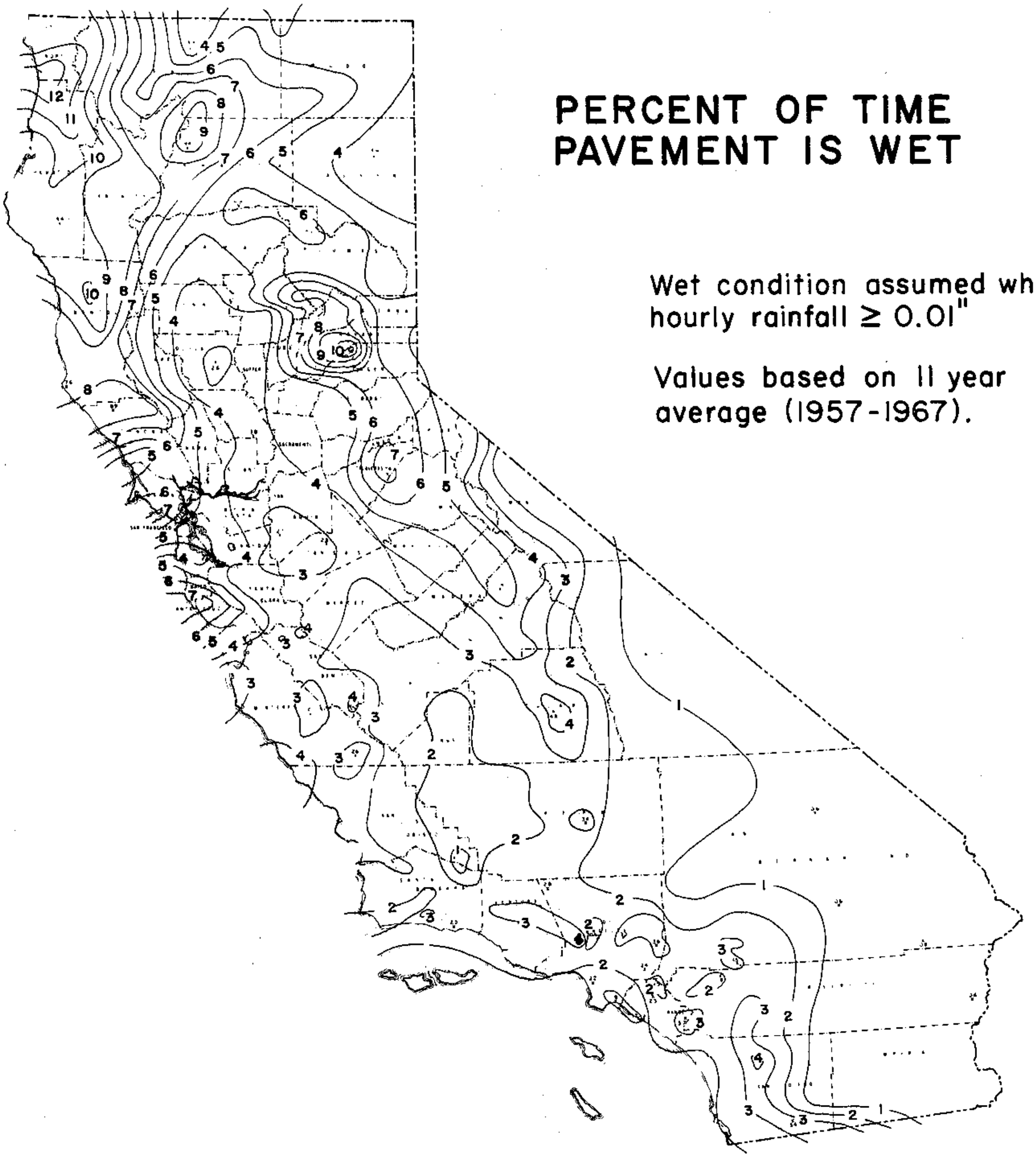
L = length including 0.2 mile downstream (miles)

(_) denotes reference material - Page 53

PERCENT OF TIME PAVEMENT IS WET

Wet condition assumed when hourly rainfall ≥ 0.01"

Values based on 11 year average (1957-1967).



When monthly ADT's are known, Equation III-1 can be sensitive to seasonal fluctuations in traffic by substituting "0.98(1-0.44R)" for "K". Wet exposure would then be:

$$WE = 0.98(1-0.44R) \cdot Pw_{0.01} \cdot AADT \cdot T \cdot L \quad \text{(Eq. III-2)}$$

The seasonal factor "R" is defined as the average summer month minus the average winter month divided by the annual average daily traffic. Or, expressed in terms of all monthly counts the equation form becomes:

$$R = \frac{(\Sigma C_{sm}) - (\Sigma C_{wm})}{6 \cdot AADT} \quad \text{(Eq. III-3)}$$

where ΣC_{sm} is the sum of the MADT for the six summer months, May through October; and ΣC_{wm} is the sum of the other six MADT's.

EXAMPLE

An urban freeway in Los Angeles has the following MADT's:

Jan	(131,924)	May	(117,422)	Sep	(145,291)
Feb	(107,788)	Jun	(109,680)	Oct	(110,315)
Mar	(101,712)	Jul	(139,608)	Nov	(120,696)
Apr	(103,776)	Aug	(161,169)	Dec	(113,157)

If we had not known the MADT's we would have assumed K=1 for an urban area and Eq. III-1 would have been:

$$WE = (1) \cdot Pw_{0.01} \cdot AADT \cdot T \cdot L$$

However, we can compute "R" from the above data. The sum of the six summer months is 783,485 vehicles; and the sum of the six other months is 679,053 vehicles. The AADT is 122,016. By Eq. III-3, R = 0.14.

By Eq. III-2 wet exposure is $WE = 0.98(1-0.44 \cdot 0.14) \cdot Pw_{0.01} \cdot AADT \cdot T \cdot L$ or, when reduced:

$$WE = (0.92) \cdot Pw_{0.01} \cdot AADT \cdot T \cdot L$$

IV. CEMENT CONCRETE GROOVING

A. General

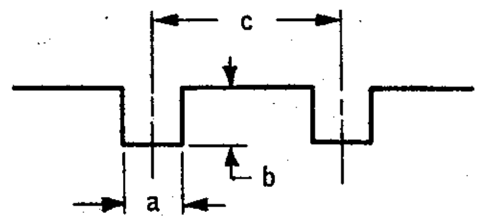
This study consisted of before and after studies of 39 grooved cement concrete projects. All of the study periods were 2 years long, except for 1 project which was 1 year long. Nine groove patterns were analyzed (See Figure 4). Adjacent sections were analyzed to indicate the effects of the wetter after periods and more traffic exposure after grooving. 2,037 accidents were included in this study which had a traffic exposure of over 794 million vehicle miles. Appendix A explains the approach to these before/after analyses of the Evaluation of Minor Improvement study.

Generally, all lanes were grooved. Only 4 of the 39 grooved cement concrete projects studied had less than all lanes grooved.

We found that grooving dividends extended about 0.2 mile downstream of the limits of grooving (See Figure 10, page 58). Thus, the accidents studied (and credited to and against grooving) include that section of ungrooved pavement 0.2 mile downstream.

CEMENT CONCRETE GROOVING PATTERNS

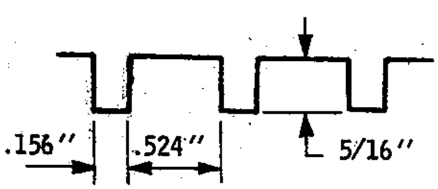
STANDARD PATTERNS



a x b x c

a	x	b	x	c
1/8″	x	1/8″	x	1″
1/8″	x	1/8″	x	3/4″
1/8″	x	3/16″	x	3/4″
3/16″	x	3/16″	x	5/8″
1/8″	x	1/8″	x	1/2″
1/8″	x	1/8″	x	3/8″

MISCELLANEOUS PATTERNS



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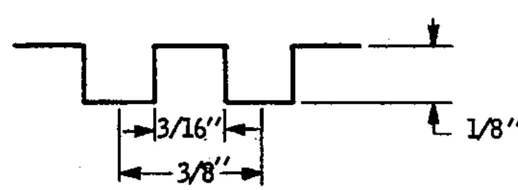

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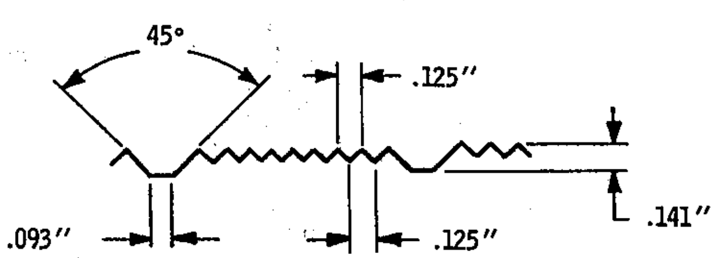


STYLE 15

B. Grooving Dividends

Our 39 projects had a total accident rate reduction of 32% and a wet accident rate reduction of 73%. Table 1 summarizes the results of the cement concrete grooving projects and their adjacent sections.

The treated sections had an average total accident rate (after) of 2.1 acc/MVM while the wet accident rate dropped from 50 acc/MVM to 13 acc/MVM.

The adjacent sections of 30 projects had a wet accident rate of 13. The only significant change in the adjacent sections was the significantly greater number of after wet accidents.

(Accident data was not on file for adjacent sections of 9 grooved projects. However, those 9 projects without adjacent sections were short sections - a total length of 1.64 miles.)

It was suspected that most "not stated" conditions were dry conditions. The miscellaneous condition included snow, flooded road, muddy, oil and loose material situations.

TABLE 1

CEMENT CONCRETE GROOVING SUMMARY

	Accidents Before	Accidents After	Accident Change	**Rates Before	**Rates After	Rate Change
Grooved Sections (39 sections)						
Wet	535	158	-70%	49.54	13.17	-73%
*Dry	560	715	+28%	1.58	1.72	+ 9%
Misc	38	31	-18%	---	---	---
Total	1,133	904	-20%	3.10	2.11	-32%
MVM	365	429 (+17%)				
Adjacent Sections (30 sections)						
Wet	101	148	+47%	9.44	12.98	+38%
*Dry	533	584	+10%	1.56	1.46	- 6%
Misc	16	22	+37%	---	---	---
Total	650	754	+16%	1.85	1.83	- 1%
MVM	351	412 (+17%)				

* Dry accidents include "not stated" accidents

** Dry exposure equals estimated total exposure less the calculated wet exposure. Miscellaneous accidents are NOT included in either Dry or Wet accident rates. (Rates are accidents/MVM).

Table 2 summarizes the change in anticipated accidents based on adjacent section accidents. The reduction in wet and total accidents by calculating anticipated after accidents was 80% and 38%, respectively. The anticipated change in dry accidents was a 15% increase.

A follow-up study of a later, much larger sample is indicating an anticipated 59% reduction in wet accidents and no change in dry accidents. See the "Foreword" for preliminary data of follow-up study. Dry accidents are analyzed further beginning on page 33.

TABLE 2

ANTICIPATED CHANGE IN ACCIDENTS

ON CEMENT CONCRETE GROOVED SECTIONS

Type	Actual After	*Anticipated After Acc.	Anticipated Less Actual After Acc.	Anticipated Change
Wet	158	784	626	-80%
Dry	715	622	93	+15%
Total	904	**1,458	554	-38%

*Assumes same percent change in accidents would have occurred in treated sections as did occur in adjacent sections. For example, from Table 1, there were 46.5% more after wet accidents than before accidents in the adjacent sections:

$$\frac{148 - 101}{101} = 46.5\% \text{ increase in wet accidents of adjacent sections}$$

$$535 \times 1.465 = 784 \text{ anticipated after accidents}$$

**Since the proportion of wet to dry accidents of the treated sections is different than that proportion for adjacent sections, the anticipated total after accidents is assumed to be the sum of wet, dry, and miscellaneous anticipated.

PERCENT CHANGE IN TOTAL ACCIDENT RATES
OF CC GROOVING

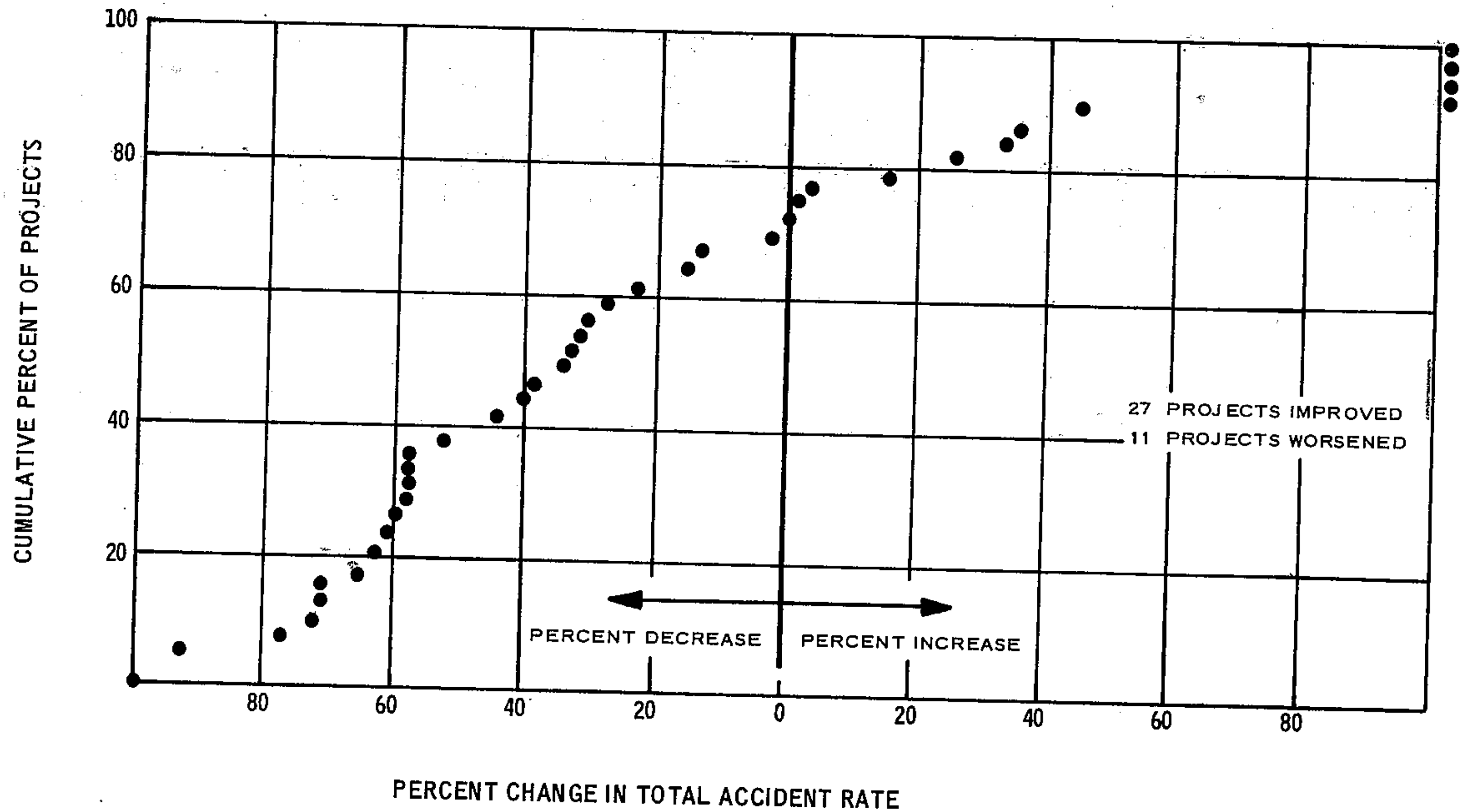


Figure 5

If anticipated accidents or rate changes are not used, caution should be used when relating accident reductions. A 1-year before and after study will have different reductions than a 2-year before and after study simply because of an increase in traffic during the study periods. A conglomeration or mixture of before and after studies having varying lengths of time may not give you much!

If you look at the 39 projects individually, we see that grooving is not a cure-all even though the overall accident reduction is significant. There were 11 projects that did not improve (See Figure 5).

C. Significance

Significance was measured by the Chi Square statistical test. The increase in traffic was taken into account by using "expected accidents". The Chi Square test was used at a 10% probability level and one degree of freedom. (See Appendix "A" for background.)

Table 3 summarizes the plots of Figures 6A through 6D. Five percent of the treated sections worsened <u>significantly</u> while 35% improved significantly. Seventy-two percent of the treated projects improved. The same number of adjacent projects worsened as improved; 14 adjacent projects worsened, 2 had no change, and 14 improved in the after period.

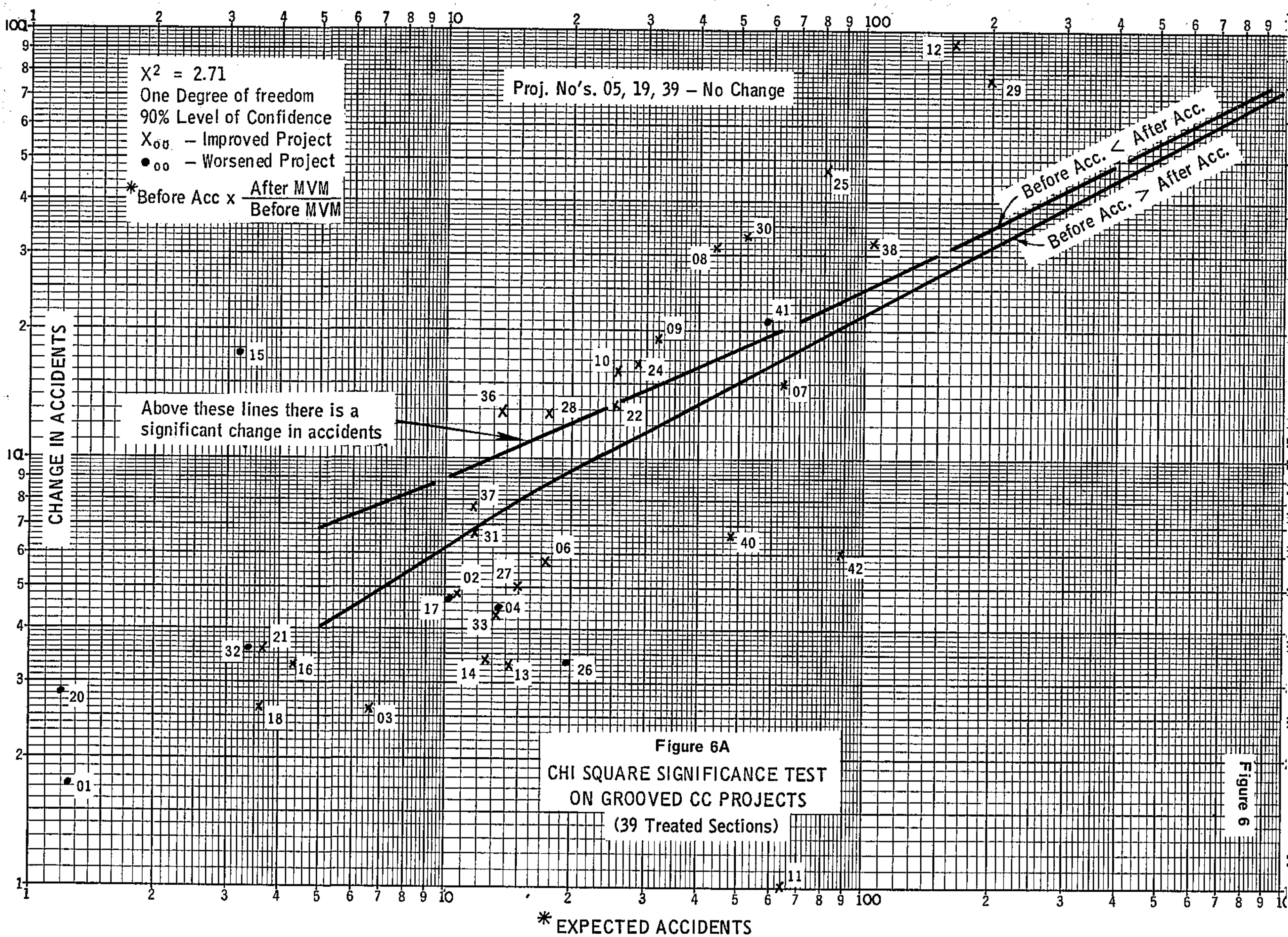


Figure 6A

CHI SQUARE SIGNIFICANCE TEST ON GROOVED CC PROJECTS (39 Treated Sections)

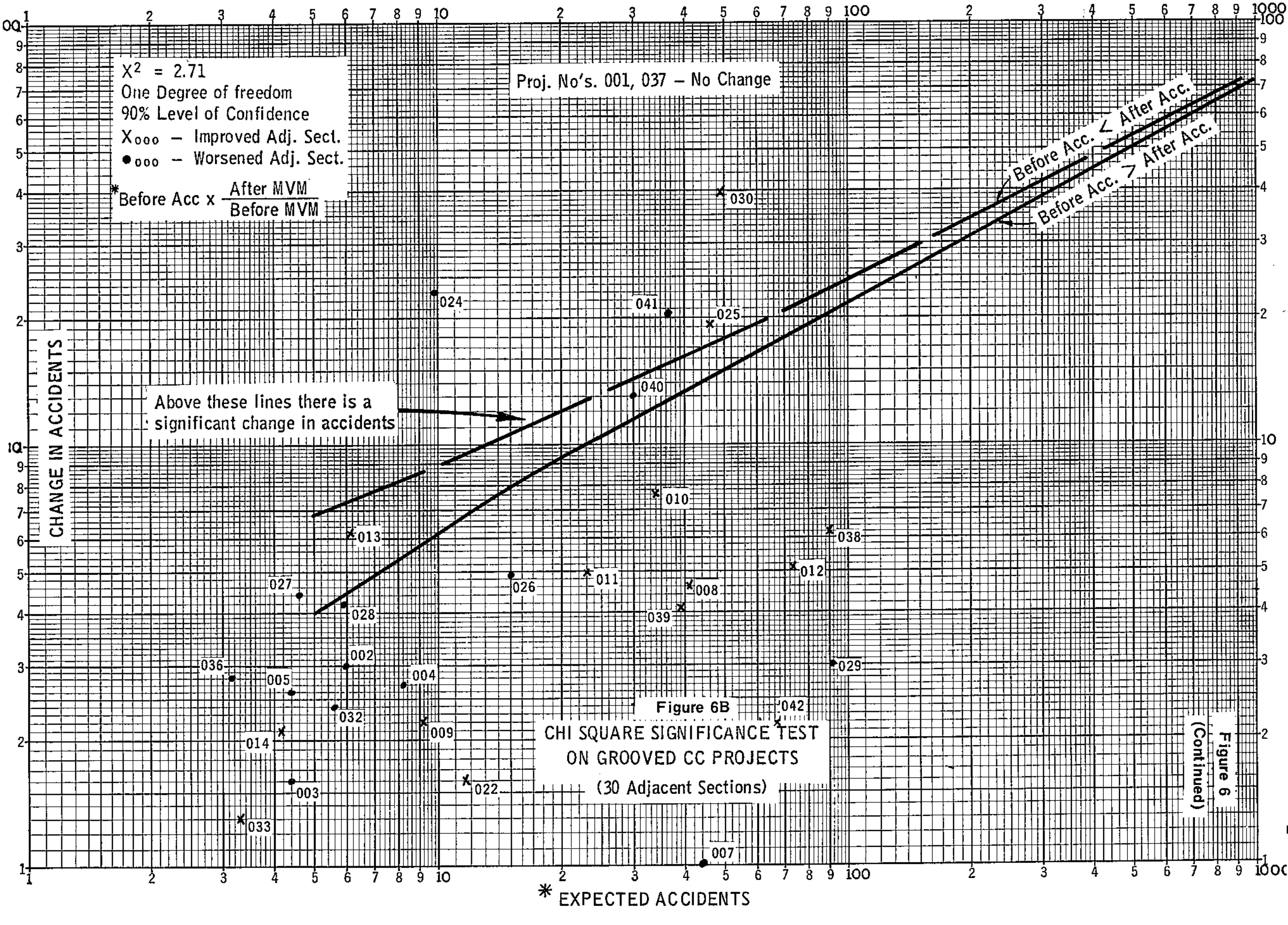


Figure 6B
CHI SQUARE SIGNIFICANCE TEST ON GROOVED CC PROJECTS
(30 Adjacent Sections)

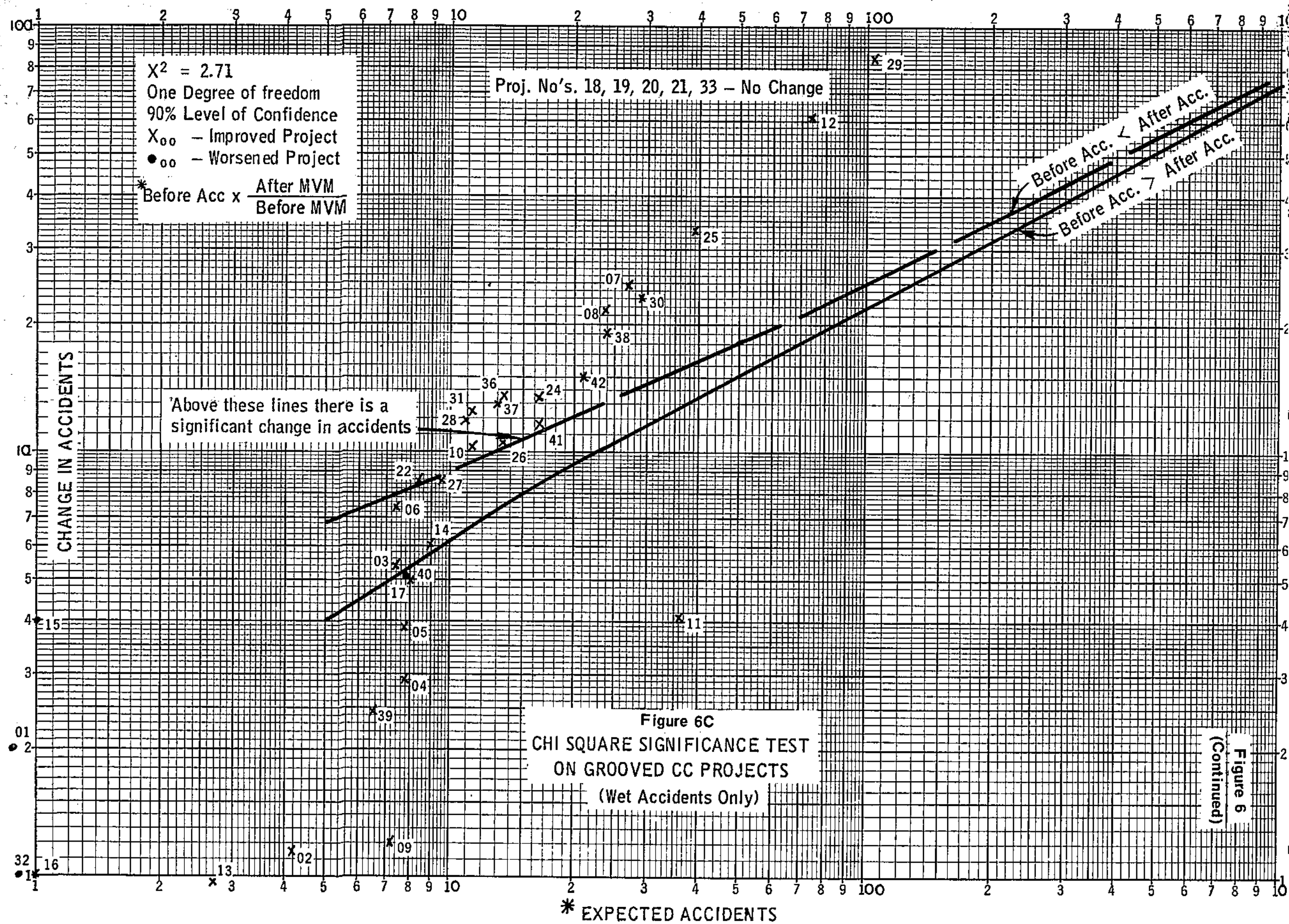


Figure 6C
CHI SQUARE SIGNIFICANCE TEST ON GROOVED CC PROJECTS
(Wet Accidents Only)

Figure 6 (Continued)

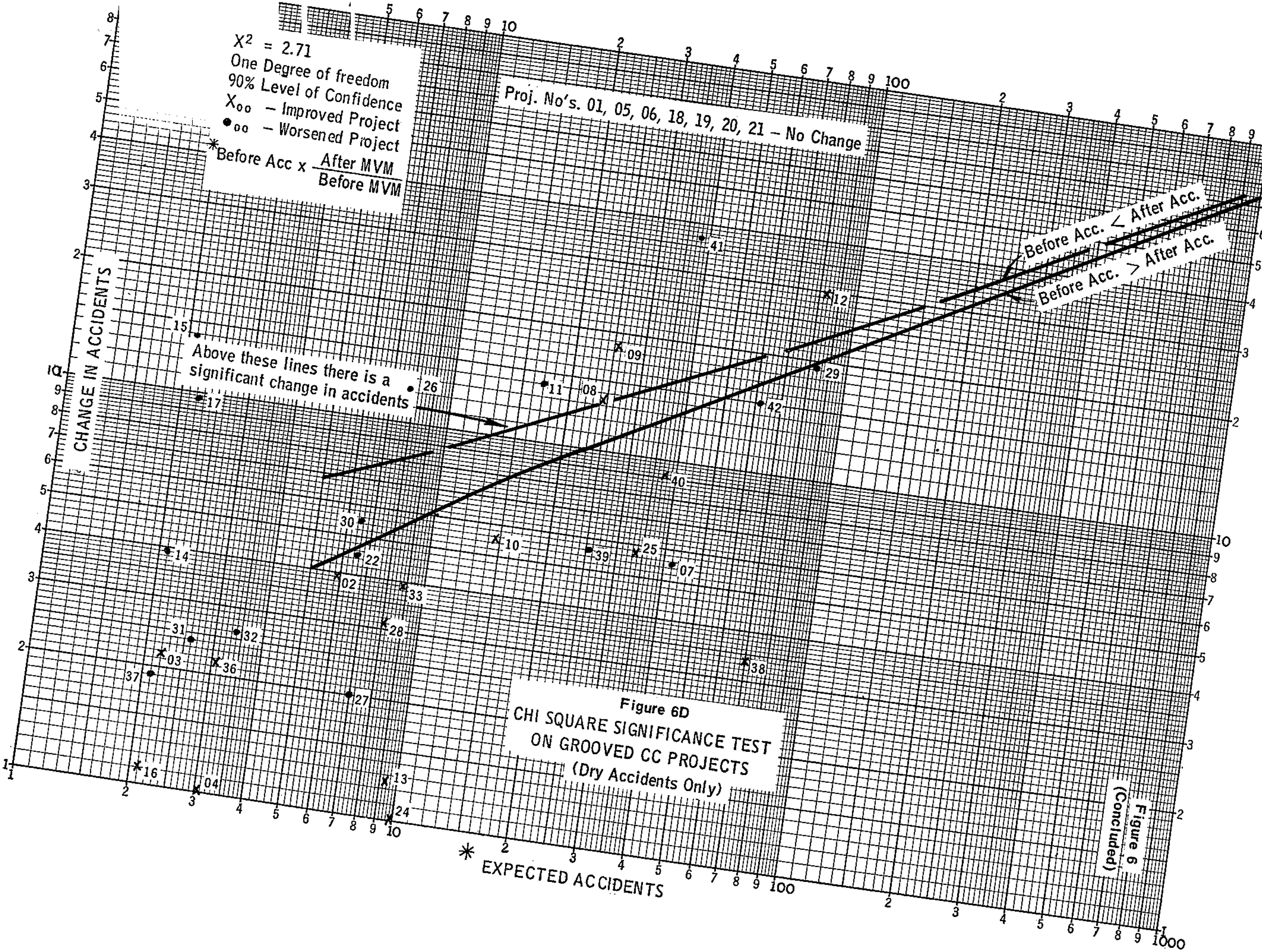


Figure 6D
CHI SQUARE SIGNIFICANCE TEST ON GROOVED CC PROJECTS (Dry Accidents Only)

Figure 6 (Concluded)

TABLE 3

SIGNIFICANCE OF CC GROOVING PROJECTS

	Improved	No Change	Worse	Significantly Improved	Significantly Worse
(Projects by Total Acc--Treated and Adjacent Sections)					
Treated Sections	28(72)	3(8)	8(20)	14(36)	2(5)
Adjacent Sections	14(47)	2(6)	14(47)	3(10)	2(7)
(Projects by Wet Acc--Treated Sections Only)					
	30(77)	5(13)	4(10)	21(54)	0(-)
(Projects by Dry Acc--Treated Sections Only)					
	16(41)	7(18)	16(41)	3(8)	5(13)

( ) denotes percent

On 77% of the projects, wet accidents were fewer after grooving. There were more wet accidents after grooving on 10% of the projects. Fifty-four percent of the projects (wet accidents) improved significantly, while none worsened significantly. On the other hand, the same number (16) of projects had more dry accidents after grooving as had less dry accidents.

D. Accidents by Grooving Pattern

We categorized our projects by grooving pattern in Table 4. The 3/4" spaced grooves gave the best results. The 1" spacing and 1/2" spacing reductions seemed to bracket the 3/4" spacing results. Both 1/2" and 1" spaced patterns still had good reductions but not nearly that of either 3/4" pattern. It would appear that the extra depth of the 1/8 x 3/16 x 3/4" pattern had no particular effect except perhaps additional life to the grooving. Three-sixteenth-inch deep grooves are being specified at the present in the Los Angeles area where pavements are subjected to considerable more wear.

TABLE 4

ACCIDENTS BY GROOVING PATTERN ON CEMENT CONCRETE

Pattern	Wet B	Wet A	**Dry B	**Dry A	*Total B	*Total A	Percent Change Wet	Percent Change Dry	Percent Change Total
1/8·1/8·1(7)	37	14	22	25NS	73	63NS	-62	+14	-14
1/8·1/8·3/4(12)	322	84	259	279NS	590	365	-74	+8	-38
1/8·3/16·3/4(2)	32	4	54	58NS	88	62	-88	+7	-30
3/16·3/16·5/8(2)	13	5	11	14NS	26	20NS	-62	+27	-23
1/8·1/8·1/2(6)	112	38	191	291	308	330NS	-66	+52	+7
1/8·1/8·3/8(7)	9	8NS	10	32	24	43	-11	+220	+79
Miscellaneous(3)	10	5NS	13	16NS	24	21NS	-50	+23	-12

* Includes "miscellaneous" accidents

** Includes "not stated" accidents

B = Before; A = After; ( ) Indicates number of projects

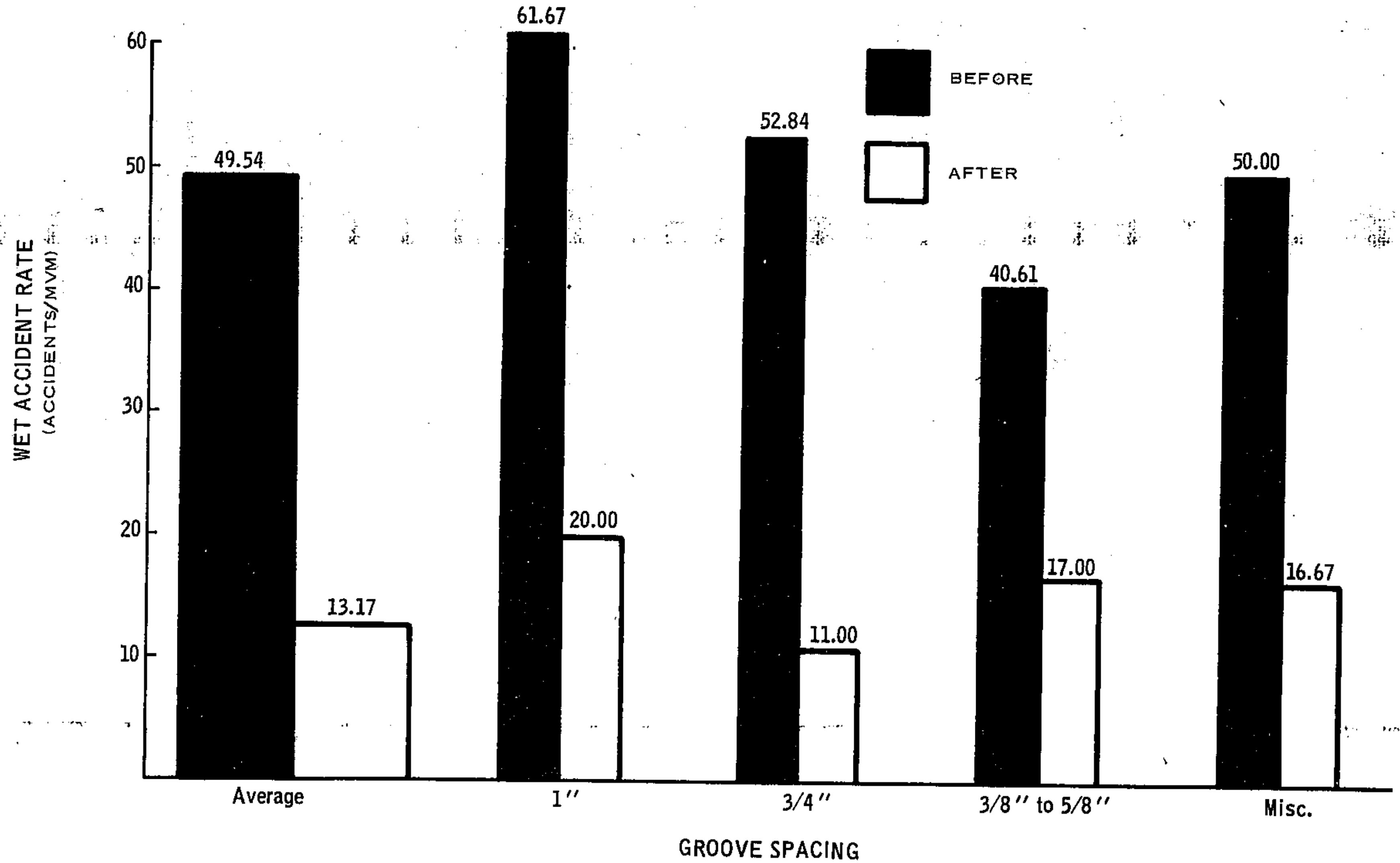
NS - Not significant (See Figure 6)

Patterns were: width·depth·groove spacing

Figure 7 illustrates the variation in wet accident rates by groove spacing. Again the 3/4" spacing was superior, even though those sections had next to the highest before rates. The higher before accident rate of the 1" spacing perhaps explains why its after accident rate was still higher. The after wet accident rates of all the categories, except 3/4", were in the approximate range of 17 to 20.

Figure 7

WET ACCIDENT RATES FOR CC GROOVING PATTERNS



The after wet accident rate of the 3/4" patterns was not much lower than the average after wet accident rate of 13 acc/MVM. Many of the individual projects had after wet accident rates around 12 acc/MVM.

The sample is small and we would have been hard pressed in defining a difference between the two 3/4" patterns. The smaller spacings did not seem to yield good reductions at all.

E. Dry Pavement Accidents

There were more dry accidents after grooving; even after allowing for traffic increases. However, as indicated earlier in Table 3, there were the same number of improved as worsened projects. Those projects with a high number of dry accidents and substantially more after dry accidents were analyzed further.

All types of vehicles, except pickup and panel types, had a proportionate increase in accidents in the after period (See Table 5). Pickup and panel vehicles represented 4% of the dry before accidents but 8% of dry after accidents.

There were more total accidents after grooving on these 7 projects; yet, the number of severe accidents decreased. There were 154 fatal and injury accidents before grooving and 142 after grooving.

TABLE 5

VEHICLES INVOLVED IN DRY ACCIDENTS

ON 7 CC GROOVED PROJECTS

(Projects Nr's. 11, 22, 26, 29, 30, 41, 42)

Type of Vehicle	Accidents Before	Percent of Bef-Total	Accidents After	Percent of Aft-Total
Standard Cars	113	64%	189	59%
Small Cars	49	28%	90	28%
Pickups and Panels	7	4%	27	8%
Total Passenger	169	96%	306	95%
Tractors and Semitrailers	3	2%	5	2%
Trucks	3	2%	7	2%
Buses	-	-	-	-
Total Commercial	6	*3½%	12	4%
Motorcycles	1	½%	3	1%
**Total Vehicles	176	100%	321	100%
Pickup and Panels Involved in Acc. on Adjacent Sections	40		42	

* Based on total commercial vehicles

** Type of vehicle was not defined in 7 before and 8 after accidents

The inference of this project's data that dry accidents might be more numerous after grooving contradicted logic! A sample of 158 more lane miles of grooving was analyzed. This larger sample's change in dry accidents was identical to its control section. That is, there was neither an increase or decrease in dry accidents as a result of grooving.

F. Severity of Accidents

Table 6 illustrates the severity trend. The fatal category had the largest decrease of any of the categories. There were less than half as many fatal accidents after grooving than before grooving!

The proportion of the various types of severity is shown in Figure 8. Fatal and injury accidents amounted to 41% of the before grooving accidents and 37% of the after grooving accidents. The Statewide percentage for full freeway (and 33 of the 39 projects were that) fatals and injuries is 39.6%.

Table 6B compares the experience of our grooved sections to the expected ranges of severity on a statewide basis. There were more before fatals than expected but a normal percentage of after fatal accidents. The percentage of fatal plus injury accidents were normal before grooving and slightly below the expected range after grooving.

TABLE 6

SEVERITY OF COLLISION - TOTAL ACCIDENTS ON GROOVED CC

TABLE 6A

ACCIDENT AND RATE CHANGES

	Accidents Before	Accidents After	Accident Change	*Rates Before	*Rates After	Rate Change
Grooved Sections						
Fatal	21	10	-52%	0.06	0.02	-67%
Injury	437	326	-25%	1.20	0.76	-37%
F + I	458	336	-27%	1.25	0.78	-38%
Pdo	675	568	-16%	1.85	1.32	-29%
Total	1,133	904	-20%	3.10	2.11	-32%
Adjacent Sections						
Fatal	7	11 NS	+57%	0.02	0.03	+50%
Injury	241	262 NS	+ 9%	0.69	0.64	- 7%
F + I	248	273 NS	+10%	0.71	0.66	- 7%
Pdo	402	481 NS	+20%	1.15	1.15	+ 2%
Total	650	754 NS	+16%	1.85	1.83	- 1%

TABLE 6B

EXPECTED RANGE OF ACCIDENTS ON GROOVED FULL FREEWAY BY SEVERITY BASED ON THE STATEWIDE PERCENT OF SEVERITY FOR FULL FREEWAY AT AN 85% LEVEL OF CONFIDENCE WITH THE POISSON DISTRIBUTION

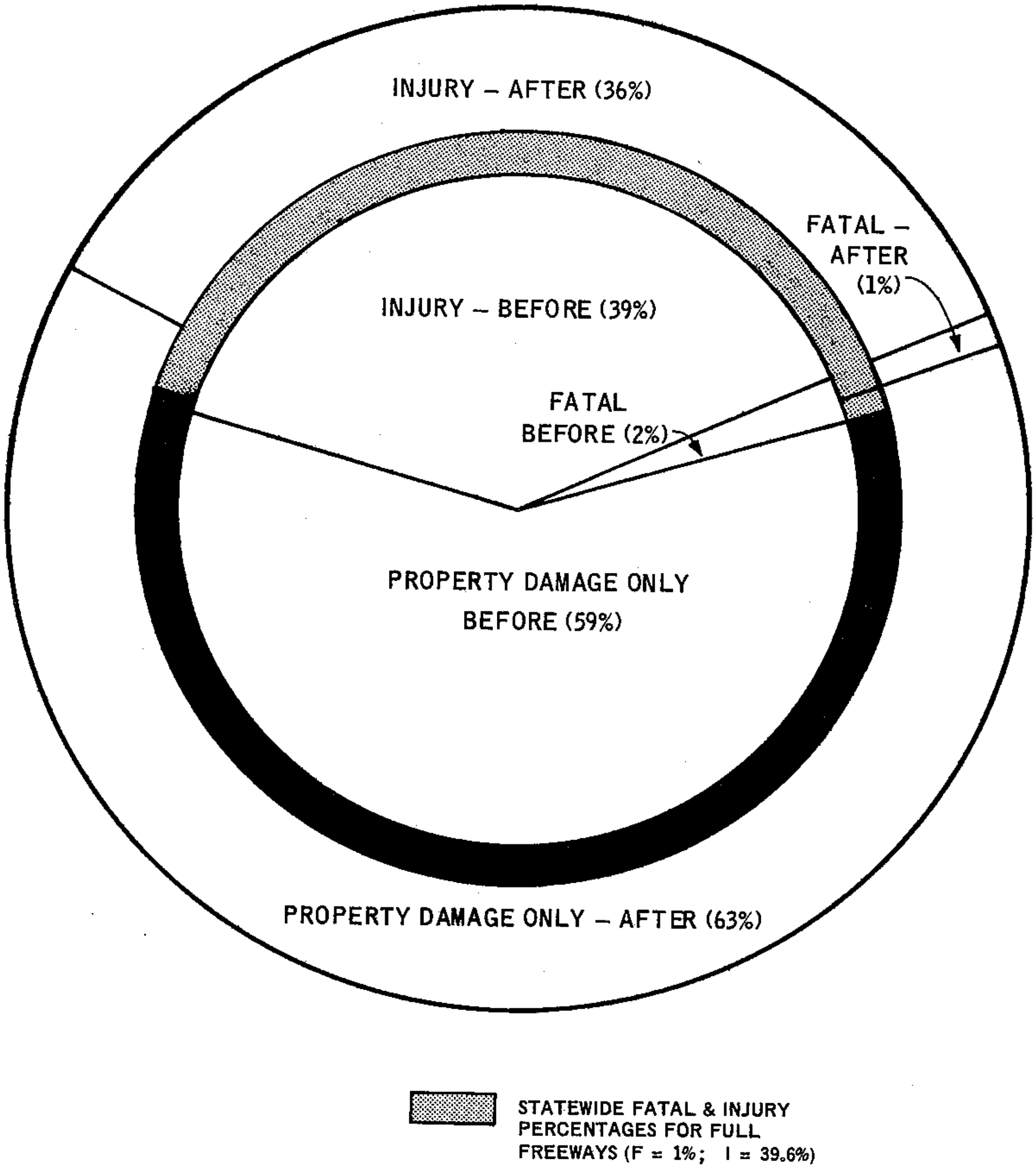
	Actual Before	Expected Before Range	Actual After	Expected After Range
Fatal	21	6 to 16	10	4 to 14
Injury	437	418 to 480	326	330 to 386
F + I	458	428 to 492	336	339 to 395
Pdo	675	635 to 711	568	499 to 575
Total	1,133		904	

* Rates based on total exposure (acc/MVM).

NS-Not significant (See Figure 6).

ACCIDENT SEVERITY – TOTAL

GROOVED CEMENT CONCRETE



G. Type of Accidents

The next question is: What is happening by type of accident? Table 7 summarizes 4 types of accidents (rear-end, head-on, hit-object and miscellaneous). All 4 types of accidents were reduced fairly uniformly in the wet pavement accident category. The deviation from the average in the dry pavement accident category was hit object and, unfortunately, miscellaneous.

It is our contention that grooving "tracks" cars and keeps them on the road. So, instead of skidding off the road and hitting a fixed object, more of the out-of-control vehicles continue along the road's alignment and collide with another vehicle. Thus there was 10% less hit object but 8% more rear-end accidents.

The miscellaneous type of accidents increased too much! Miscellaneous accidents were 1) noncollision, 2) broadside, 3) pedestrian, 4) overturned and 5) other or undetermined. A random check was made of 30 of the larger Portland cement concrete projects. Only 2 categories of miscellaneous accidents deviated from the trends of Table 7. They were 4) overturned, and 5) other or undetermined of the "dry" accident type.

TABLE 7

TYPE OF COLLISION

GROOVED CEMENT CONCRETE

	Accidents Before	Accidents After	Accident Change	**Rates Before	**Rates After	Rate Change
Total Accidents						
Rear-end	381	362	- 5%	1.04	0.84	-19%
Head-on	15	8	-47%	0.04	0.02	-50%
Hit Object	623	377	-39%	1.71	0.88	-49%
Miscellaneous	114	157	+38%	0.31	0.37	+19%
Total	1,133	904	-20%	3.10	2.11	-32%
***Dry Accidents**						
Rear-end	235	295 NS	+26%	0.66	0.71	+ 8%
Head-on	6	7 NS	+17%	0.02	0.02	0%
Hit Object	254	271 NS	+ 7%	0.72	0.65	-10%
Miscellaneous	65	145	+123%	0.18	0.35	+94%
Total	560	718 NS	+28%	1.58	1.72	+ 9%
Wet Accidents						
Rear-end	135	57	-58%	12.50	4.75	-62%
Head-on	7	1	-86%	0.65	0.08	-88%
Hit Object	353	90	-75%	32.69	7.50	-77%
Miscellaneous	40	10	-75%	3.70	0.83	-78%
Total	535	158	-70%	49.54	13.17	-73%

*Includes not stated accidents

**Rates are based on total exposures (acc/MVM)

NS - Not significant (See Figure 6)

The "overturn" accidents increased slightly on dry pavement (24 to 35) in our sample. This was understandable since the grooves could tend to trip a car skidding across them. (I might note here that the wet pavement condition of these same projects yielded 8 before overturns to 4 after overturns.)

The "other or undetermined" type increased from 20 before dry accidents to 77 after dry accidents. A perusal of those 97 accidents revealed there had been a change in accident reporting in the after period. Some law enforcement zones in the southern part of the State began using a very abbreviated report form for minor "property damage only" accidents in early 1969 (during the "after" period of our study). Seventy-one of the above 77 after accidents were of this type. There is no description or sketch of these accidents. It was not possible to categorize these "short form" accidents. We suspect that more "minor" accidents were reported after the introduction of the short form than were before its availability.

This change in reporting does leave us with one observation, however. There is not a like increase in wet-miscellaneous accidents. In fact, the reduction in wet-pavement miscellaneous accidents is about the same as that for the wet-pavement total change.

Figure 9 shows these same 4 categories as a proportion of the total. The hit-object type decreased while rear-end and miscellaneous types increased. The head-on type of accident did not change.

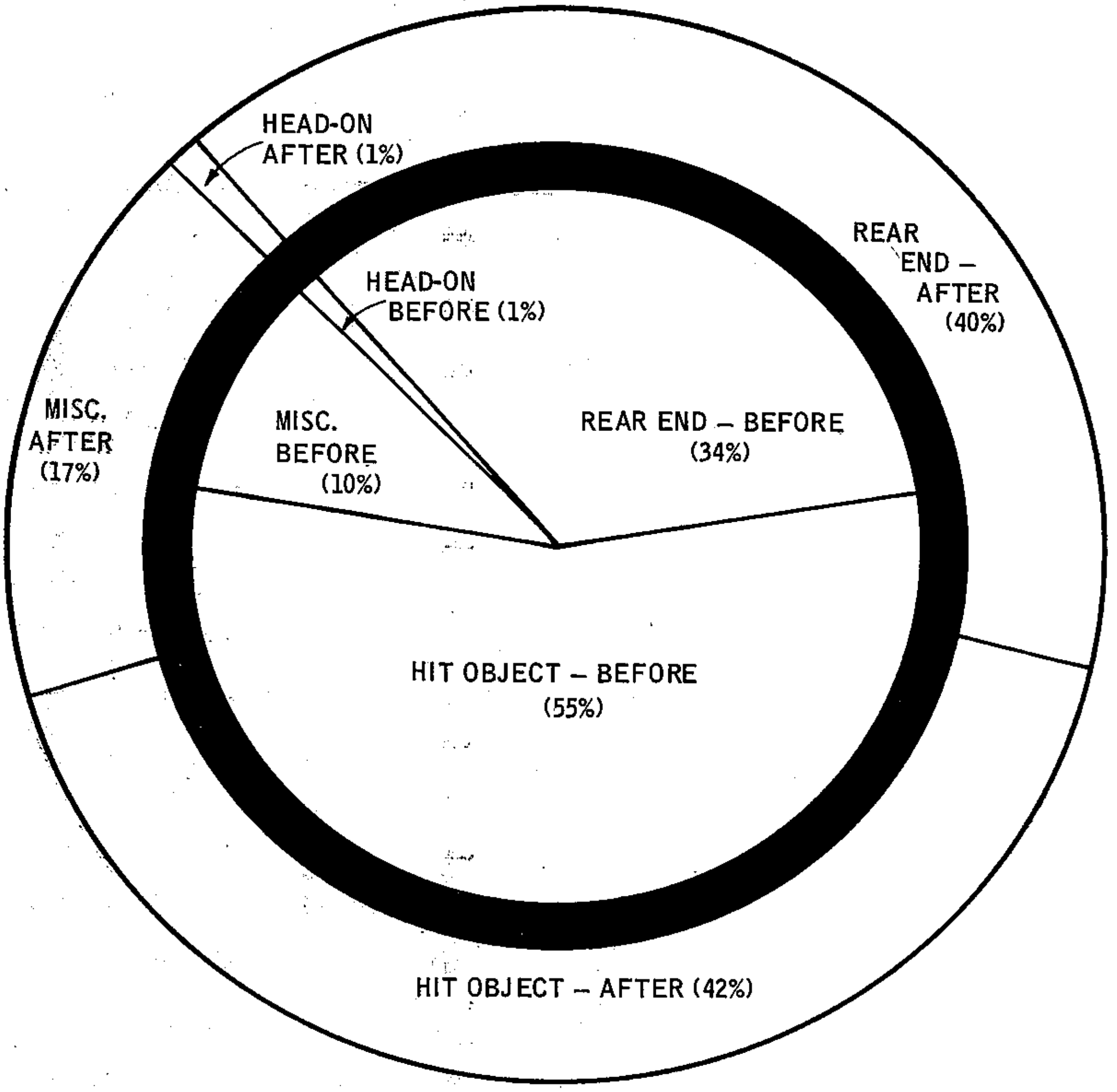
We theorized above that the increase in miscellaneous accidents was due to an increase in minor property damage accidents of undetermined type on dry pavement. We cannot determine their type but we might suspect the usually less severe "rear-end" type of accident (which had also increased).

H. Alignment

We looked at the alignment of our 39 projects but there were too many combinations to really analyze them in depth.

The projects seemed pretty well distributed by horizontal alignment with no particular direction or size of curve more prevalent than another. It would appear that curves to the right might be more sensitive to wet accidents as they had higher before and after wet accident rates. This could possibly be caused by the dynamics of a vehicle (i.e., torque of motor). It could be the fact that a driver sits on the left side of his car and has a better feel for curves to his left. In addition, the right lanes are exposed to more traffic wear.

TYPE OF ACCIDENTS ON
GROOVED CEMENT CONCRETE



Except for small radius right curves, the after wet accident rate drops to between 5 and 6 accidents per MVM on level and miscellaneous vertical grades.

Approximately 2/3 of our projects had 1% or less grades. Downgrades showed little change after grooving but had low wet accident rates to begin with. Upgrades and level sections had about the same reduction, that is, 75% to 80%.

Upgrades had higher wet accident rates before and after. This is not too surprising! Skidding and loss of control is related to the available "grip" between pavement and tire. Part of that grip is required for traction or power transmitted through the tire when you go upgrade, thus reducing your margin of safety.

I. Density

The density of traffic must have some effect on accidents so we compared projects by vehicles/hour/lane. About 85% (33) of our projects carried less than 1/2 capacity. The accident reduction was greater for the heavier traveled roads.

J. Friction

This study was not set up to study friction factors. As a consequence, very few factors were available for analysis. Those values that were available would not relate to accidents at all. Sections with higher friction factors did not always yield better reductions.

There were initial increases in friction after grooving but that was likely caused by the sharp edges of new grooves. The edges were usually worn down by traffic in short order and "f" returned to about what it was before. Before friction values ranged between 0.20 and 0.30 for those few sections where they were available.

However, a wet accident reduction still occurred despite little change in friction factors; probably because escape paths for water were created by the grooves. Secondly, longitudinal grooves probably act as mini-railroad tracks providing resistance against lateral movement. (Transverse grooves would not have done that.) The tread in the pavement redeems to some degree those drivers with not enough sense to have tread on their tires!

V. ASPHALT CONCRETE GROOVING

California has a few grooved asphalt concrete pavements in service and is beginning to groove more asphalt concrete surfaces. Grooving of very brittle, older asphalt concrete surfaces has been successful. The same equipment and construction methods are used to groove asphalt concrete as are used to groove cement concrete surfaces. Probably, the success of grooved asphalt concrete was due to the fact that the aggregate was grooved in the process. Asphalt does tend to flow back into the grooves of soft, new asphalt concrete and bleeding asphalt concrete pavement will continue to bleed and slicken after grooving.

Two sections of asphalt concrete in the Los Angeles area have been grooved 5 years. They should stand up for at least two more years. The State of Colorado (8) had less success on a section of asphalt concrete overlay. It kneaded over in 4 months but was not full-depth, old asphalt concrete.

Four of California's oldest grooved AC sections were studied. All 4 treated AC projects improved, and improved significantly. Two adjacent sections improved and 2 worsened.

(_) denotes reference material - Page 53

The accident reduction was greater on these 4 sections of asphalt concrete than on cement concrete. Wet accidents were reduced 80% while total accidents decreased 46%. And, traffic did not increase nearly as much as it had within the CC sections studied. There was only 6% more traffic in the after periods of the 4 grooved AC projects.

We suspect that the reductions developed from the 39 grooved cement concrete projects would be more applicable to grooved asphalt concrete projects in general than those reductions obtained from 4 grooved asphalt concrete projects.

If AC pavement is to be grooved, we recommend that those results obtained from the study of grooved cement concrete pavements be applied to grooved asphalt concrete pavements except for the groove life. The life of grooves in AC is very speculative and could last from a few months to as much as 10 years. California uses 5 years.

VI. PREDICTING ACCIDENT REDUCTIONS

The 3/4" spaced grooving gave the best results and is our current specification. Since 14 of our study projects were on 3/4" spacing we confined our pursuit of a predictor to these projects. Closer analysis showed one project, Project #11, to be completely out of line with the others and it was dropped from the following analysis.

Some 58 variables of traffic and weather characteristics were submitted to multiple regression analysis to determine which parameter would best predict after wet accidents. The best fitting linear relationship took the following equation form:

$$WAR_A = 1.32 + 3 \cdot DAR_B \qquad \text{(Eq. VI-1)}$$

where WAR_A is Wet Accident Rate After; DAR_B is Dry Accident Rate Before.

The coefficient of correlation squared (r^2) was 0.67, and the standard error of estimation was 4.2. Thus, using DAR_B as a predictor of WAR_A will reduce the total sum of squares of deviations by 67%. Two-thirds of the after wet accident rates can be expected to be within 4.2 of the predicted value.

The before period traffic exposures are determined by first calculating the actual number of hours of 0.01 inch or more precipitation in the vicinity of the proposed project.

Converting this to percent of wet time gives (Pw_{Actual}) which can be used in Equation III-1 from page 16 for wet exposure. Dry exposure is total exposure less wet exposure.

The expected wet accident rate after grooving is calculated by Equation VI-1 and subtracted from the before wet accident rate to determine the wet accidents eliminated per wet pavement MVM. "After" wet travel is based on a $Pw_{0.01}$ taken from Figure 3 on page 17.

Based on the data presented in the "Foreward", it is assumed that grooving has no effect on dry accidents. Unless there are extenuating circumstances such as an unusual number of dry pavement, skidding accidents, dry accident rates should not change after grooving. The tracking effect of the longitudinal grooves can reduce dry pavement, skidding accidents.

Another premise is that the severity of accidents will be similar to Statewide averages after grooving. (Our study indicated slightly lower severities than Statewide averages but not <u>significantly</u> lower severities at an 85% confidence level of the Poisson Statistical Test).

Lastly, Equation VI-1 is based on data that includes 0.2 mile of ungrooved pavement downstream of the proposed grooving. To ignore the accident reduction in this 0.2 mile will discount some of the benefits derived from grooving.

The first step, of course, is to locate a wet pavement problem. Low skid numbers might suggest a location should be evaluated. A concentration of several wet pavement, skidding accidents is also a good indicator. If the percent of wet accidents for a section of road is higher than the Statewide or area percentage, investigation is needed. Once the limits of a proposed project have been established, Figure 10 can be completed to determine accident reductions.

FIGURE 10

REDUCTION IN WET PAVEMENT ACCIDENTS

Col. 1	2	3	4	5	6	7	8
TOTAL TRAVEL MVM	% WET TIME	WET TRAVEL MVM	DRY TRAVEL MVM	NO. OF WET ACC/YR.	NO. OF DRY ACC/YR.	WET ACC. RATE	DRY ACC. RATE
(a)	Actual	EqIII-1	(1-3)			(5÷3)	(6÷3)

9	10	11	12	13
EXPECTED % WET TIME	EXPECTED WET TRAVEL MVM	EXPECTED WET ACC. RATE	REDUCTION IN WET ACC. RATE	NO. OF WET ACC. RED/YR
FIG. 3	Eq. III-1	(b)	(7-11)	(10 x 12)

(a) Total Travel = AADT x Study length x 365 days

(b) $WAR_A = 1.32 + 3 \times DAR_B$ where DAR_B is Col. 8

Equation III-1: $WE = K \cdot Pw_{0.01} \cdot AADT \cdot T \cdot L$

The next step is to determine the life of your grooving. California uses 10 years for CC pavement and 5 years for old, brittle AC pavement grooved 1/8-inch deep. Soundness of aggregate, traffic exposure and condition of pavement have to be taken into consideration.

California allows for changes in traffic by calculating a volume correction factor (VCF). The VCF is the average AADT for the expected life of the grooving divided by the present AADT.

The total number of wet accidents reduced is:

Total accidents reduced = VCF x Grooving Life x Annual Accident Reduction (Eq. VI-2)

NOTE: Since we assumed no change in dry accidents, the number of wet accidents reduced is also the total number of accidents reduced.

SAMPLE CALCULATION

We suspect a section of urban freeway in central Los Angeles County to have a wet-accident problem. We propose to use the current 0.095" x 0.125" x 0.75" grooving pattern on this tangent section of Portland cement concrete. The following information is known about the before period:

AADT is 103,000 veh/day;
length of project is 0.85 mile;
seasonal factor (R)** is zero;
study period is 3 years.

wet accidents = 108*
dry accidents = 132*

Actual wet time is 4%

The following information was estimated for the after period:

Life expectancy of grooving is 10 years;
AADT 10 years hence is 157,000;
By Figure 3, $Pw_{0.01}$ = 2.5%.

Figure 10 will be completed as follows:

Col. 1 Tot. Tvl. = 0.103 x (0.85 + 0.20) x 365 = 39.47 MVM

Col. 2 Pw = 0.04 (given)

Col. 3 Wet Tvl. = 0.98 (1-0.44 x 0) x 0.04 x 39.47 = 1.55 MVM

Col. 4 Dry Tvl. = 39.47 - 1.55 = 37.92 MVM

Col. 5 No. of Wet Acc/Yr. = 108 ÷ 3 = 36

Col. 6 No. of Dry Acc/Yr. = 132 ÷ 3 = 44

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*Includes accidents 0.2 mile downstream.

** The average summer month's MADT equaled the average winter month's MADT, therefore there was no seasonal change in traffic. If we had not known MADT's, we would have assumed K=1 for an urban freeway.

Col. 7 $WAR_B = 36 \div 1.55 = 23.23$ Acc/MVM

Col. 8 $DAR_B = 44 \div 37.92 = 1.16$ Acc/MVM

Col. 9 $Pw_{EX} = 0.025$ (given)

Col. 10 Wet $Tvl_{EX} = 0.98 (1-0.44 \times 0) \times 0.025 \times 39.47 = 0.97$ MVM

Col. 11 $WAR_{EX} = 1.32 + 3 \times 1.16 = 4.80$

Col. 12 $WAR_{RED} = 23.23 - 4.80 = 18.43$

Col. 13 No. Wet Acc. Red/Yr. = $0.97 \times 18.43 = 17.9$

Col. 1	2	3	4	5	6	7	8
TOTAL TRAVEL MVM	% WET TIME	WET TRAVEL MVM	DRY TRAVEL MVM	NO. OF WET ACC/YR.	NO. OF DRY ACC/YR.	WET ACC. RATE	DRY ACC. RATE
(a)	Actual	EqIII-1	(1-3)			(5÷3)	(6÷3)
39.47	0.04	1.55	37.92	36	44	23.23	1.16

9	10	11	12	13
EXPECTED % WET TIME	EXPECTED WET TRAVEL MVM	EXPECTED WET ACC. RATE	REDUCTION IN WET ACC. RATE	NO. OF WET ACC. RED/YR
FIG. 3	Eq. III-1	(b)	(7-11)	(10 x 12)
0.025	0.97	4.80	18.43	17.9

$VCF = (0.157 + 0.103) \div (2 \times .103) = 1.26$

Total accidents reduced by grooving this project would be: $1.26 \times 10 \times 17.9 = 225.5$ accidents.

$\boxed{225.5 \text{ accidents}}$

VII. REFERENCES

1. Kummer, H. W., and Meyer, W. E., "Tentative Skid-Resistance Requirements for Main Rural Highways", National Cooperative Highway Research Program Report 37, 1967.

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APPENDIX A

EVALUATION OF MINOR IMPROVEMENT STUDIES

A. General

Data from some 500 minor improvement projects were gathered for the 10 parts of the "Evaluation of Minor Improvements" study. These were then classified and analyzed. The previous publications were:

Part	Title	Date Published
1.	Flashing Beacons	May 1967
2.	Safety Lighting	May 1967
3.	Delineation	Jul 1967
4.	Guardrail	Jul 1967
5.	Left-Turn Channelization	Oct 1967
6.	Signs	May 1968
7.	Traffic Signals	Apr 1970
9.	Open Graded Asphalt Concrete Overlays	Jan 1972
10.	Miscellaneous	Jan 1972

B. Study Objectives

The 3 objectives of the "Evaluation of Minor Improvements" study were:

1. To determine the effectiveness of minor improvements in reducing traffic accidents.
2. To determine what conditions are susceptible to improvement and how much improvement can be expected.
3. To determine methods and measures for predicting the magnitude of the accident reduction on proposed minor improvement projects.

No "cost per accident reduced" analysis has been made herein. California's methodology to determine savings due to predicted reductions in accidents is described in another publication of the Division of Highways.(11)

C. Study Methodology

The "before" and "after" accidents and accident rates were compared. The "accident rate" was simply the number of accidents related to vehicle exposure. (Million vehicle miles were used except for spot or intersection improvements where number of all entering vehicles were used.)

To avoid bias due to seasonal fluctuations in accidents, the same calendar months were used in the before and after periods when fractional parts of any year were used (e.g., May 1966 to December 1967 Before; and May 1968 to December 1969 After).

In before and after studies the possibility always exists that a project may be initiated because of an unusually short time peak accident experience. The peak might be a "temporary" condition in the before period or merely a random fluctuation of accidents. In such cases, even if nothing had been done, an accident reduction would probably have been observed in the "after" period (regression to the mean theory).

(_) denotes reference material - Page 53

The possibility of such an influence was investigated and it was found that most projects were the result of sustained high levels of accident experience. Additionally, the time interval between recognition of the problem and the beginning of construction was usually long enough to eliminate most temporary conditions from the before periods. This, in effect, should have resulted in samples which were "unbiased" in the before period.

An interval of time was skipped between completion of construction and initiation of the after period to allow traffic to stabilize. This should have given us an "unbiased" after period. <u>The construction period was never included in either the before or after periods</u>.

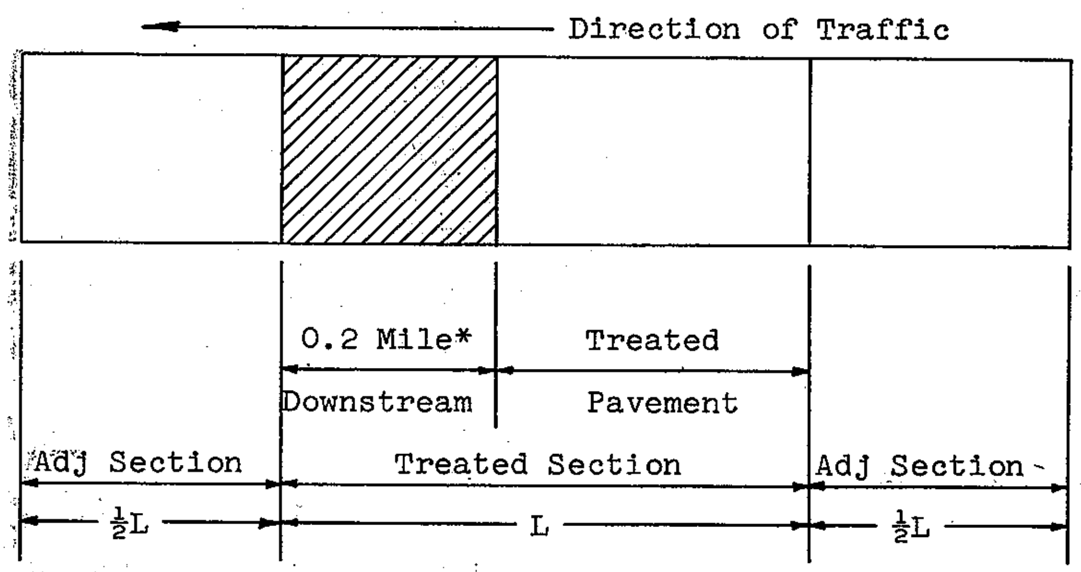
Often, long-term biases or trends can influence before and after conditions. These trends can be a change in road use, increase in traffic, or even a change in the weather to name a few.

In order to visualize these long-term biases or trends, accidents within adjacent sections were reviewed. Adjacent sections were defined to include roadway contiguous to the project. The adjacent sections had a traffic exposure as nearly equal to that of the treated sections as was possible (See Figure 11).

We assumed that treated sections would have had the same change in accidents as their adjacent sections "if" they had not been treated. We took the percent change in adjacent section accidents and multiplied that by treated section "before" accidents to determine expected or anticipated after accidents. The difference between anticipated after accidents and actual after accidents should be our true change due to improvement alone, if our adjacent and treated sections were identical "except for the treatment".

FIGURE 11

PROJECT LIMITS



*Grooving and overlay projects only

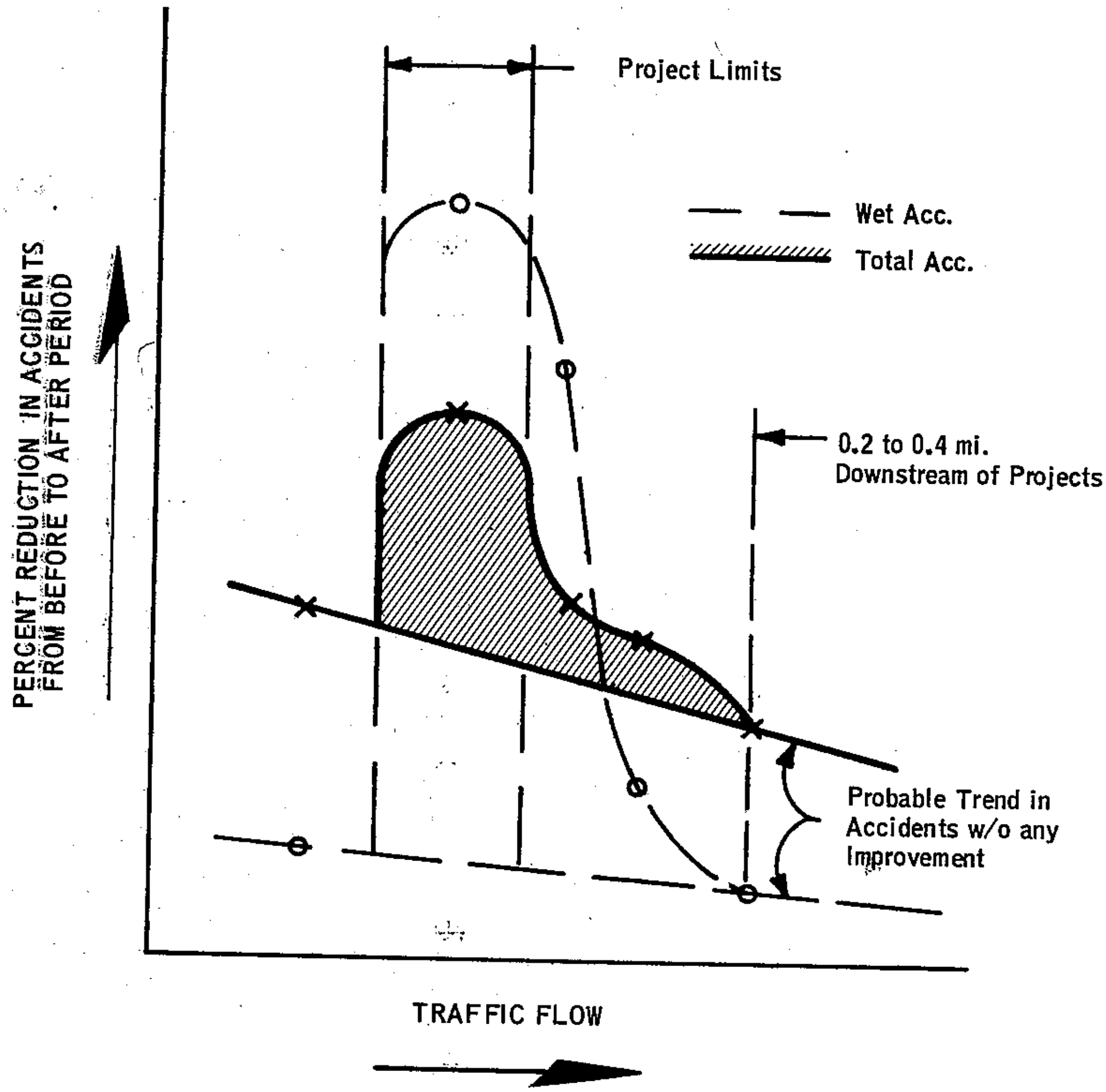
The "point of impact" or location of accidents was often misleading; especially in the case of wet accidents. At speeds in excess of 60 mph a vehicle can go out of control and move many hundred feet downstream before becoming involved in a collision. Experience in grooving was beginning to indicate that grooving should begin a good distance upstream of wet pavement accident concentrations and before and after studies should include accidents a distance downstream.

If grooving was not carried sufficiently upstream, accidents may be reduced at the location of concentration but not as significantly as anticipated. Drivers still lost control, as in the before period, yet some of them regained control when they reached the grooved surface. Hence, a token improvement was yielded.

Fifteen portland cement concrete grooving projects of this Part 8 study had sufficiently long, adjacent sections to analyze accidents upstream and downstream of the projects. The length of those 15 projects varied from 0.21 mile to 1.31 miles. (All before and after periods were 2 years.) There was a uniform concentration of accidents 0.1 mile upstream and between 0.1 and 0.2 mile downstream. A higher concentration of accidents was indicated between the end of project and 0.1 mile downstream. Figure 12 gives a schematic representation of the influence of grooving on downstream accidents.

INFLUENCE OF GROOVING ON ADJACENT SECTIONS

PERCENT CHANGE IN ACCIDENTS VERSUS LOCATION



D. Significance Testing

We were interested only in the nonrandom accidents. Nonrandom accidents were those accidents due to an "accident causation process". We had to discount those chance or random accidents that would have occurred in any case. Statistics gave us an inference of the likelihood of nonrandom events (in our case - accidents).

We established, by statistical curves, an estimate of the percent change in accidents necessary to indicate a "significant" enough change for us to conclude that there had been indeed a caused change and not a random change. A Bureau of Public Roads (now Federal Highway Administration) Circular Memorandum (12) dated April 1, 1966, suggested 2 frequently used statistical tests: Poisson Distribution and chi-square tests. Both tests have limitations and neither was universally valid for accident studies.

Both tests were plotted on Figure 13 for comparison. Note that the chi-square test was more conservative. That is, it required a higher reduction for significance at 90% certainty than the Poisson curve required at 95% certainty! (A normal distribution curve was superimposed to match the end of the Poisson curve for more than 25 expected accidents.)

We chose to use the more conservative "chi square" statistical test at a 90% level of confidence. This gave us

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( ) denotes reference material - Page 53

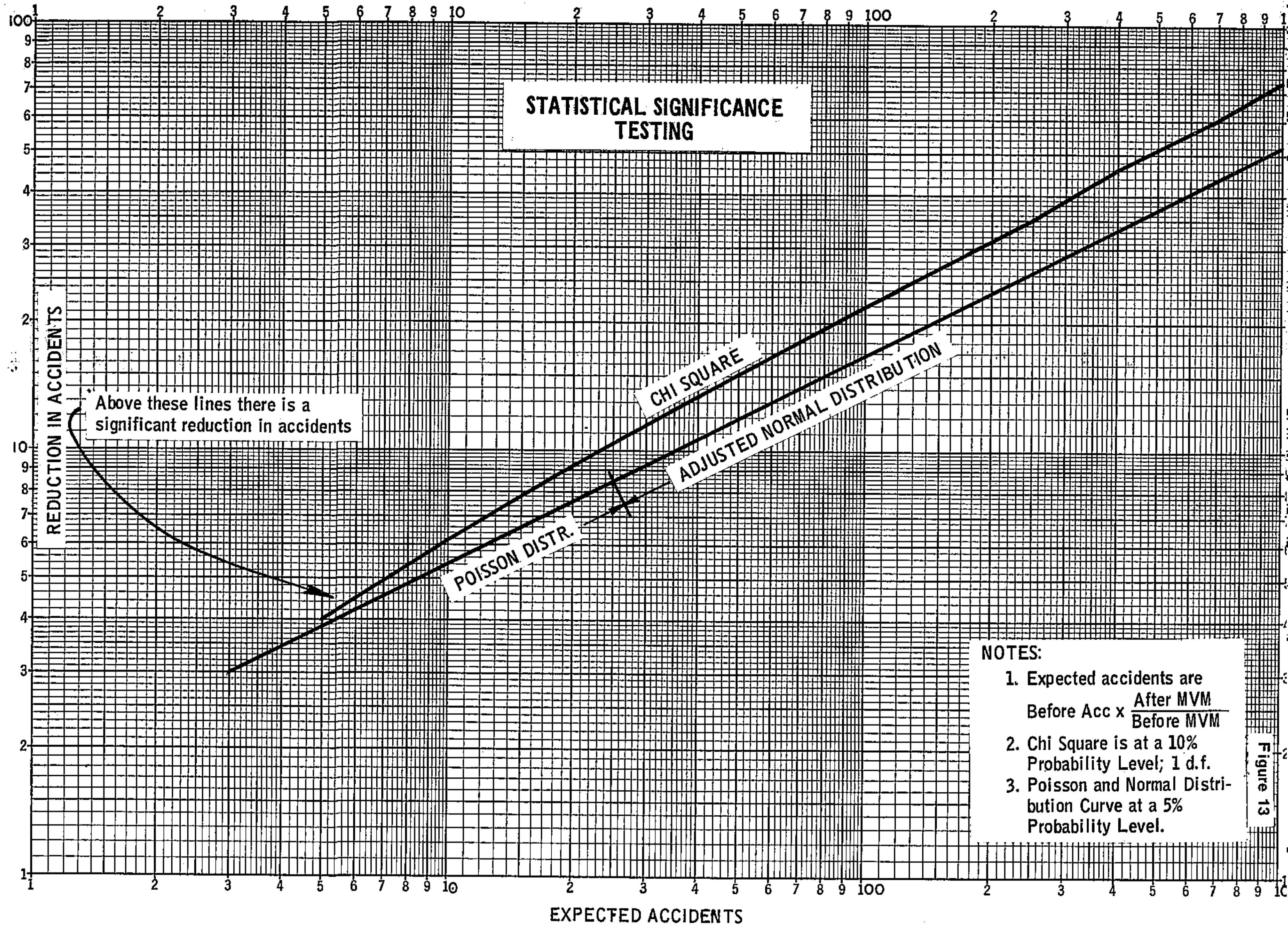
Figure 13
STATISTICAL SIGNIFICANCE TESTING
Above these lines there is a significant reduction in accidents
CHI SQUARE
ADJUSTED NORMAL DISTRIBUTION
POISSON DISTR.
REDUCTION IN ACCIDENTS
EXPECTED ACCIDENTS
NOTES:
1. Expected accidents are Before Acc x After MVM / Before MVM
2. Chi Square is at a 10% Probability Level; 1 d.f.
3. Poisson and Normal Distribution Curve at a 5% Probability Level.

results comparable to those cited in reference (12). "Yates Correction for Continuity" would have made our significance test even more conservative and was not included.

Note that there could be 2 plots; 1 where significantly more accidents occur in the after period and another where significantly less accidents occur in the after period. Both of these curves are plotted on the statistical test figures of Part 8, "Grooved Pavements", of the Evaluation of Minor Improvements study.

The chi-square curve evaluates the independence of the "after" sample to that of the "before" sample. A contingency table composed of "cells" representing all the possible combinations of treatments and responses works well as long as there are no less than 5 events in any 1 cell (13). Before and after studies can be set up in a 2 x 2 contingency table format as shown below in Table 8.

TABLE 8

CONTINGENCY TABLE FORMAT

Before Accidents	Before Non-Accidents	Before Vehicles
After Accidents	After Non-Accidents	After Vehicles
Total Accidents	Total Non-Accidents	Total Vehicles

(_) denotes reference material - Page 53

The above contingency table was the basis for the following chi square (X^2) equations:

$$X_{(1)}^2 = \frac{\left[\text{Before Acc} - \left(\text{Total Acc} \times \frac{\text{Bef Veh}}{\text{Tot Veh}}\right)\right]^2}{\left(\text{Total Acc} \times \frac{\text{Bef Veh}}{\text{Tot Veh}}\right)} \qquad \text{(Eq. A-1)}$$

$$X_{(2)}^2 = \frac{\left[\text{After Acc} - \left(\text{Total Acc} \times \frac{\text{Aft Veh}}{\text{Tot Veh}}\right)\right]^2}{\left(\text{Total Acc} \times \frac{\text{Aft Veh}}{\text{Tot Veh}}\right)} \qquad \text{(Eq. A-2)}$$

$$X_{(3)}^2 = \frac{\left[\text{Before N'Acc} - \left(\text{Total N'Acc} \times \frac{\text{Bef Veh}}{\text{Tot Veh}}\right)\right]^2}{\left(\text{Total N'Acc} \times \frac{\text{Bef Veh}}{\text{Tot Veh}}\right)} \qquad \text{(Eq. A-3)}$$

$$X_{(4)}^2 = \frac{\left[\text{After N'Acc} - \left(\text{Total N'Acc} \times \frac{\text{Aft Veh}}{\text{Tot Veh}}\right)\right]^2}{\left(\text{Total N'Acc} \times \frac{\text{Aft Veh}}{\text{Tot Veh}}\right)} \qquad \text{(Eq. A-4)}$$

$$X^2 = X_{(1)}^2 + X_{(2)}^2 + X_{(3)}^2 + X_{(4)}^2 \qquad \text{(Eq. A-5)}$$

The terms $X_{(3)}^2$ and $X_{(4)}^2$ are extremely small values since there is always a large number of nonaccidents in any accident study. Also, we preferred to substitute "exposure" for vehicles. In that way, we were able to express the chi square equations in accident and accident exposure terms. Terms involving exposure were nondimensional and could be expressed in either MV or MVM. When we reduced the chi square equations (for accidents) we had:

$$X^2 = \frac{\left[\text{Bef Acc} - \left(\text{Tot Acc} \times \frac{\text{Bef Exposure}}{\text{Tot Exposure}}\right)\right]^2}{\left(\text{Tot Acc} \times \frac{\text{Bef Exposure}}{\text{Tot Exposure}}\right)} + \frac{\left[\text{Aft Acc} - \left(\text{Tot Acc} \times \frac{\text{Aft Exposure}}{\text{Tot Exposure}}\right)\right]^2}{\left(\text{Tot Acc} \times \frac{\text{Aft Exposure}}{\text{Tot Exposure}}\right)} \qquad \text{(Eq. A-6)}$$

When before and after exposures are equal, the above equation can be reduced to:

$$X^2 = 4 \frac{(\text{Bef Acc} - \tfrac{1}{2} \times \text{Tot Acc})^2}{\text{Tot Acc}} \qquad \text{(Eq. A-7)}$$

GROOVING SPECIFICATIONS

(Delete Para. 6 if not applicable.)

(The grooved width shown on the plans should be 2 feet less than the lane width rounded to the nearest foot, except that it should never be less than 9 feet.)

GROOVE EXISTING CONCRETE PAVEMENT.--The surface of existing concrete pavement shall be grooved at the locations and to the dimensions shown on the plans. Said grooving shall conform to the requirements of these special provisions.

Grooved areas shall begin and end at lines normal to the pavement center line and shall be centered within the lane width.

Grooving blades shall be 0.095-inch wide ± 0.003-inch and shall be spaced 3/4 inch on centers. The grooves shall be cut not less than 1/8 inch nor more than 1/4 inch deep. The grooves on bridge decks shall be cut not less than 1/8 inch nor more than 3/16 inch deep.

The actual grooved area of any selected 2-foot by 100-foot longitudinal area of pavement specified to be grooved shall be not less than 95 percent of the selected area. Any area within the selected area not grooved shall be due only to irregularities in the pavement surface and for no other reason.

Residue from grooving operations shall not be permitted to flow across shoulders or lanes occupied by public traffic or to flow into gutters or other drainage facilities. Solid residue resulting from grooving operations shall be removed from pavement surfaces before such residue is blown by the action of traffic or wind.

The noise level created by the combined grooving operation shall not exceed 86 dbA at a distance of 50 feet at right angles to the direction of travel.

Pavement grooving will be measured by the square yard. The quantity of pavement grooving to be paid for will be determined by multiplying the width of the grooved area by the total horizontal length of lane grooved.

The contract price paid per square yard for groove existing concrete pavement shall include full compensation for furnishing all labor, materials, tools, equipment and incidentals and for doing all work involved in grooving the existing concrete pavement, including removing residue, as shown on the plans, as specified in these special provisions, and as directed by the Engineer.

Appendix C

SKID TREATMENT DATA

(CODES FOR TABLE)

Project Identity:

26 - project number
0 - pavement type (0-CC; 1-AC)
3 - treatment (see codes below)
2 - type of road (0-conv ; 1-express ; 2-freeways)

Treatment Codes

0 - no treatment
1 - grooved 1/4·1/4·1
2 - grooved 1/8·1/8·1
3 - grooved 1/8·1/8·3/4
4 - grooved 1/8·3/16·3/4
5 - grooved 3/16·3/16·5/8
6 - grooved 1/8·1/8·1/2
7 - grooved 1/8·1/8·3/8
8 - grooved (miscellaneous)

Alignment:

6 - horizontal alignment (see codes below)
1 - horizontal curve direction (see codes below)
0 - grade alignment (see codes below)

Horizontal Curve Codes

1 - $R < 300$-foot
2 - $300 \leq R < 550$
3 - $550 \leq R < 850$
4 - $850 \leq R < 1{,}150$
5 - $1{,}150 \leq R < 1{,}800$
6 - $R \geq 1{,}800$-foot
7 - Tangent
9 - Miscellaneous

Direction

1 - left
2 - right
3 - reversing
0 - tangent
9 - miscellaneous

Grade Codes

0 - level ($\pm 1\%$)
1 - $-1\% \leq$ Grade $< -3\%$
2 - $-3\% \leq$ Grade $< -5\%$
3 - $-5\% \leq$ Grade
4 - $\pm 1\% <$ Grade $< +3\%$
5 - $3\% \leq$ Grade $< +5\%$
6 - $+5\% \leq$ Grade
7 - crest vertical
8 - sag vertical
9 - miscellaneous

R = Seasonal Prediction Factor

APPENDIX C Continued

SKID TREATMENT DATA

PROJECT IDENTITY	ALIGNMENT	TREATED MI (×10⁻²)	NR OF LANES	YRS OF STUDY	AADT BEF. ×10²	AADT AFT. ×10²	PERCENT WET HOURS BEF. ×10⁻¹	PERCENT WET HOURS AFT. ×10⁻¹	"R" (× 10⁻²)	ACCIDENTS (B – BEFORE, A – AFTER) TOTAL B	TOTAL A	FATAL B	FATAL A	INJURY B	INJURY A	WET B	WET A	DRY B	DRY A	REAR-END B	REAR-END A	HEAD-ON B	HEAD-ON A	HIT FIXED OBJECT B	HIT FIXED OBJECT A
01022	613	021	2	2	047	055	089	102	20	001	003	1	0	00	02	000	02	01	001	00	000	00	00	00	003
01002		041	2	2	047	055	089	102	20	004	005	0	1	01	02	000	02	02	003	03	000	00	00	00	005
02022	523	014	2	2	045	054	093	107	20	009	006	1	0	04	03	003	03	05	002	03	001	01	00	04	005
02002		034	2	2	045	054	093	107	20	005	009	0	0	03	05	001	02	01	001	03	002	00	00	02	007
03022	513	017	2	2	048	053	031	068	20	006	004	0	0	05	02	003	02	02	000	01	002	00	00	05	002
03002		047	2	2	048	053	031	068	20	004	006	0	0	03	04	000	01	03	003	00	002	00	00	03	002
04022	516	010	2	2	048	050	031	068	20	013	018	2	1	09	11	003	04	03	004	03	008	00	00	08	010
04002		030	2	2	048	050	031	068	20	008	011	0	1	05	07	000	01	03	003	04	006	01	00	02	004
05022	516	013	3	2	047	052	045	055	20	007	008	1	1	03	03	005	03	00	000	01	001	00	00	06	007
05002		038	3	2	047	052	045	055	20	004	007	0	1	01	04	002	00	01	003	03	003	00	00	01	003
06022	510	044	2	2	033	045	062	056	20	013	012	1	0	05	06	006	00	05	007	00	001	00	00	08	010
07042	520	032	3	2	334	411	042	054	20	052	049	0	0	15	17	017	02	34	047	27	027	01	00	23	006
07002		052	3	2	334	411	042	054	20	036	045	1	2	12	21	006	11	30	034	14	022	00	00	20	014
08042	510	032	3	2	334	411	042	054	20	036	013	0	0	16	02	015	02	20	011	17	007	01	00	14	005
08002		052	3	2	334	411	042	054	20	033	036	1	0	10	13	005	04	27	032	17	010	02	00	12	018
09032	620	014	2	2	312	360	052	054	10	023	013	1	0	16	04	006	06	22	007	07	004	01	00	19	008
09002		034	2	2	312	360	052	054	10	008	007	0	0	02	03	004	02	04	005	02	006	00	00	05	001
10032	610	027	3	2	406	455	052	052	10	023	010	1	0	11	03	010	01	13	009	11	005	00	00	12	005
10002		047	3	2	406	455	052	052	10	030	026	0	0	08	10	001	03	29	023	18	016	00	00	11	008
11032	420	013	2	2	220	282	066	053	20	050	063	0	0	20	23	035	32	13	031	18	027	00	00	32	034
11002		033	2	2	220	282	066	053	20	018	018	0	0	07	03	000	04	18	014	12	012	01	00	05	006
12032	620	006	4	2	513	597	054	051	10	140	069	2	0	51	23	067	13	72	055	83	055	01	00	42	008
12002		026	4	2	513	597	054	051	10	063	068	0	0	33	23	010	16	52	052	50	050	02	00	07	013
13051	523	008	2	2	058	059	074	065	30	014	011	3	0	05	05	003	02	09	008	01	001	00	00	10	008
13001		028	2	2	058	059	074	065	30	006	000	0	0	01	00	000	00	06	000	03	000	01	00	02	000
14051	516	008	2	2	058	060	074	065	30	012	009	0	0	02	05	010	03	02	006	01	005	00	00	09	003
14001		028	2	2	058	060	074	065	30	002	002	0	0	02	01	001	01	01	001	00	000	00	00	01	002
15072	610	004	2	2	079	084	024	023	30	003	021	0	0	01	11	001	05	02	016	01	001	00	00	02	015
16072	520	004	2	2	077	083	024	023	30	004	001	0	0	02	01	001	00	02	001	03	001	00	00	00	000

APPENDIX C Continued

SKID TREATMENT DATA

PROJECT IDENTITY	ALIGNMENT	TREATED MI (× 10⁻²)	NR OF LANES	YRS OF STUDY	AADT BEF. ×10²	AADT AFT. ×10²	PERCENT WET HOURS BEF. ×10⁻¹	PERCENT WET HOURS AFT. ×10⁻¹	"R" (× 10⁻²)	ACCIDENTS (B – BEFORE, A – AFTER): TOTAL B	TOTAL A	FATAL B	FATAL A	INJURY B	INJURY A	WET B	WET A	DRY B	DRY A	REAR-END B	REAR-END A	HEAD-ON B	HEAD-ON A	HIT FIXED OBJECT B	HIT FIXED OBJECT A
17072	630	048	2	2	084	096	030	030	25	009	015	0	1	02	10	007	03	02	012	03	005	00	01	02	004
18072	700	008	2	2	082	099	033	035	20	003	001	0	0	01	00	000	00	01	001	01	000	00	00	00	001
19072	700	008	2	2	082	099	033	035	20	001	001	0	0	00	00	000	00	01	001	00	000	00	00	00	001
20070	700	014	1	2	019	023	033	034	26	001	004	0	1	01	03	000	00	01	001	00	002	00	00	00	001
21070	700	014	1	2	019	023	033	034	26	003	000	0	0	02	00	000	00	01	000	00	000	02	00	00	000
22022	708	015	4	1	636	667	038	018	06	024	012	0	0	12	07	017	00	06	011	04	006	00	00	18	005
22002		035	4	1	636	667	038	018	06	011	010	0	0	03	03	005	01	06	009	04	004	00	00	07	006
24032	610	027	4	2	465	512	029	024	06	026	012	0	0	09	04	018	03	08	008	07	001	00	00	12	007
24002		047	4	2	465	512	029	024	06	009	033	0	0	02	06	005	18	04	015	01	011	00	00	07	019
25032	410	016	4	2	798	788	030	025	02	082	034	3	0	31	13	048	06	34	028	26	016	00	00	38	014
25002		036	4	2	798	788	030	025	02	046	026	2	0	14	10	002	05	44	021	36	015	01	00	03	009
26032	610	069	3	2	200	231	028	033	10	017	023	1	1	07	11	010	03	07	020	03	007	00	00	11	013
26002		089	3	2	200	231	028	033	10	013	020	0	0	03	07	001	07	12	013	08	007	00	00	03	009
27032	610	036	3	2	208	242	028	033	10	013	010	0	0	07	03	007	01	06	009	06	002	00	00	07	005
27002		056	3	2	208	242	028	033	10	004	009	1	1	00	02	000	01	04	008	01	004	01	00	02	003
28032	620	034	3	2	209	244	028	033	10	015	005	0	1	05	02	008	00	07	005	02	000	00	00	10	003
28002		054	3	2	209	244	028	033	10	005	010	0	0	03	03	000	04	05	006	00	006	00	00	03	002
29032	639	120	4	2	742	852	025	024	06	172	121	0	1	64	37	094	19	72	102	66	064	02	01	98	052
29002		140	4	2	742	852	025	024	06	080	095	0	0	36	39	011	13	69	082	38	047	01	00	36	037
30062	620	022	3	2	190	245	036	026	10	040	019	0	0	15	08	031	06	05	012	05	008	00	00	29	011
30002		042	3	2	190	245	036	026	10	038	009	0	0	19	03	015	03	22	006	06	001	00	00	21	006
31081	610	020	2	2	063	083	023	028	10	009	005	0	0	06	01	007	00	02	005	01	000	00	00	08	001
32080	610	004	1	2	121	136	033	038	10	003	007	0	0	02	02	000	01	03	006	02	004	00	01	01	001
32000		024	1	2	121	136	033	038	10	005	008	0	1	02	02	001	00	04	007	05	003	00	00	00	001
33080	620	004	2	2	122	136	033	038	10	012	009	2	0	05	06	003	04	08	005	05	002	03	03	02	002
33000		024	2	2	122	136	033	038	10	003	002	0	0	02	00	000	00	03	002	00	001	00	00	01	001
34112	639	024	5	2	690	723	028	021	04	162	055	0	0	78	35	113	05	49	050	79	030	03	01	43	018
34102		044	5	2	690	723	028	021	04	047	033	0	0	24	18	015	09	32	024	27	021	00	00	13	011
35112	639	034	5	2	678	709	028	021	04	082	053	2	0	29	28	048	21	34	032	29	030	01	01	24	018

APPENDIX C Concluded

SKID TREATMENT DATA

PROJECT IDENTITY	ALIGNMENT	TREATED MI (×10⁻²)	NR OF LANES	YRS OF STUDY	AADT BEF. ×10²	AADT AFT. ×10²	PERCENT WET HOURS BEF. ×10⁻¹	PERCENT WET HOURS AFT. ×10⁻¹	"R" (×10⁻²)	ACCIDENTS (B – BEFORE, A – AFTER) TOTAL B	TOTAL A	FATAL B	FATAL A	INJURY B	INJURY A	WET B	WET A	DRY B	DRY A	REAR-END B	REAR-END A	HEAD-ON B	HEAD-ON A	HIT FIXED OBJECT B	HIT FIXED OBJECT A
35102		054	5	2	678	709	028	021	04	080	094	0	1	35	49	020	32	60	062	32	050	01	00	25	035
36032	621	029	3	2	146	155	030	038	00	013	001	1	0	08	01	010	00	03	001	00	000	00	00	11	000
36002		049	3	2	146	155	030	038	00	003	006	0	1	02	02	002	02	01	004	00	001	00	01	03	003
37032	614	025	3	2	129	136	024	033	00	011	004	0	0	05	02	009	00	02	004	03	002	01	01	06	001
37002		045	3	2	129	136	024	033	00	003	003	1	0	01	01	000	01	03	002	02	001	00	00	01	002
38062	639	131	4	2	360	457	026	018	10	082	072	0	2	23	20	027	05	55	067	24	021	00	01	52	033
38002		151	4	2	360	457	026	018	10	071	084	0	1	27	33	008	11	62	072	29	039	00	00	38	025
39062	701	031	4	2	400	505	026	019	10	027	034	0	0	15	08	006	03	20	031	14	016	01	00	08	012
39002		051	4	2	400	505	026	019	10	031	035	0	0	07	07	010	09	21	026	11	010	00	00	18	012
40062	611	046	4	2	334	398	026	019	10	040	041	0	0	16	14	009	13	31	028	06	011	00	00	33	021
40002		066	4	2	334	398	026	019	10	025	043	0	1	06	14	005	09	20	034	09	015	00	02	15	018
41062	529	055	4	2	344	433	026	020	10	047	080	0	0	14	24	017	05	30	075	16	026	00	00	30	026
41002		075	4	2	344	433	026	020	10	029	057	1	1	10	21	003	11	26	045	12	032	00	01	13	012
42062	619	061	4	2	346	433	026	020	10	072	084	1	1	22	29	022	06	50	078	10	023	01	00	53	034
42002		081	4	2	346	433	026	020	10	053	064	0	0	16	13	003	06	50	058	33	029	00	00	18	014
43131	613	033	2	1	115	118	025	044	10	009	001	1	0	02	01	006	00	03	001	02	000	01	00	06	009
43101		053	2	1	115	118	025	044	10	003	002	0	0	02	02	000	00	03	002	00	001	00	00	03	000
44132	620	116	4	1	632	670	011	037	04	114	088	1	0	61	48	042	16	72	072	61	050	00	01	35	030
44102		136	4	1	632	670	011	037	04	053	072	1	2	29	30	009	20	44	052	27	034	02	04	19	023